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(NASA-CR-161770) COAL LIQUEFACTION PROCESSES AND DEVELOPMENT REQUIREMENTS ANALYSIS FOR SYNTHETIC FUELS PRODUCTION Final Report (Spectra Research Systems, Inc.) 157 p HC A08/MF A01 CSCL 21D

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# COAL LIQUEFACTION PROCESSES AND DEVELOPMENT REQUIREMENTS ANALYSIS FOR SYNTHETIC FUELS PRODUCTION

OCTOBER 15, 1980

SRS/SE ETR80-12

## FOREWORD

This final report is submitted to the George C. Marshall Space Flight Center (MSFC), National Aeronautics and Space Administration (NASA) by Spectra Research Systems, 555 Sparkman Drive, Suite 608, Huntsville, Alabama, 35805. This document provides a synopsis of the results of a three-month study contract (NAS8-34046) conducted under the technical guidance of Dr. Shelba Proffitt (MSFC) as part of the NASA Headquarters-Energy Systems Division's Energy Technology Program.

Technical questions concerning this report should be directed to Mr. John D. Hyde (205/830-0375).

Contributors

| | |
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## TABLE OF CONTENTS

## LIST OF FIGURES

## 1.0 INTRODUCTION

The diminishing world reserves of oil and natural gas, increasing rates of consumption, and the continuing uncertainties of price and supply of these fuels has underscored the need to develop alternate hydrocarbon fuels. An official at the Department of Energy has stated, "The critically low level of our oil reserves with respect to consumption demands is a major reason why oil imports have risen so high. This nation needs to turn this situation around, and it is our mission in fossil energy to develop technologies in support of this shift." The conversion of coal into synthetic gaseous and liquid fuels in an economically viable and environmentally acceptable manner represents a major future commercial alternative to conventional fuels.

Full commercial scale coal liquefaction facilities do not exist in this nation today. If such facilities are to become technically, economically, and environmentally viable, advanced technology must be developed and implemented in coal liquefaction processes and systems. This study focused on: (a) developing a technical and programmatic data base on direct and indirect liquefaction processes which have potential for commercialization during the 1980's and beyond, and (b) performing analyses to assess technology readiness and developments trends, development requirements, commercial plant costs, and projected synthetic fuels costs. Numerous data sources and references were used as the basis for the analysis results and information presented.

The major study inputs and products are summarized in Figure 1-1.

The two categories of liquefaction processes have the following characteristics:

- Indirect Liquefaction
  - Coal is gasified to produce synthesis gas ($H_2$, CO)

- Reacted with catalysts to produce liquids
- Conversion efficiency 45-60% (Fischer-Tropsch: 1.6-1.7 barrels/ton, methanol synthesis: 2.2-2.5 barrels/ton)
- Liquid products are relatively pollutant free (sulfur, oxygen, nitrogen removed as $H_2S$, $H_2O$, $NH_3$)

- Direct Liquefaction
  - Coal is reacted directly with hydrogen source catalyst
  - Processes differ in the mechanics of the reactor and/or kind of catalyst used (e.g., cobalt molybdate, silica-promoted aluminum, other metal oxides)
  - Solid and liquid products must be separated to remove unreacted coal and waste ash
  - Conversion efficiency 65-70% (2.5-3 barrels/ton)

Liquefaction processes in both of the above categories were described and analyzed in this study.

### INPUTS

- DOE PROGRAM/PROJECT REPORTS
- DOE ENERGY TECH. CENTERS (METC, PETC, ETC.) DEVEL. PROJECTS DATA
  - IN HOUSE
  - CONTRACTED
- NASA FOSSIL ENERGY ACTIVITIES/PRIOR STUDIES
  - MSFC
  - LeRC
  - JPL
- PILOT PLANT OPERATOR DATA
- PROCESS VENDOR DATA
- SRS ENERGY DATA BASE
  - PROCESS DESCRIPTIONS
  - PROGRAMMATICS/SCHEDULES
  - COMPARISON/EVAL. MATRIX

### PRODUCTS

- COAL LIQUEFACTION PROCESS DATA BASE
  - TECHNICAL
  - PROGRAMMATIC
- COAL LIQUEFACTION SYSTEMS DATA BASE
  - OPERATIONAL STATUS
  - DEVELOPMENT STATUS
- REQUIREMENTS FOR ADVANCED TECHNOLOGY APPLICATIONS
  - SYSTEMS/EQUIPMENT
  - INSTRUMENTATION/CONTROLS
  - MATERIALS
- DOE TECHNOLOGY DEVELOPMENT SUMMARY
- ECONOMIC ASSESSMENT

FIGURE 1-1. STUDY INPUTS AND PRODUCTS

## 2.0 COAL LIQUEFACTION PILOT AND SUBSCALE DEMONSTRATIONS

Coal liquefaction processes can be categorized into three groupings according to the level of technology employed:

- o First generation are processes which were developed prior to World War II and have been operating commercially since that time.
- o Second generation are processes which incorporate improved technology to increase conversion efficiency and reduce plant capital costs. Most of these processes have been demonstrated in pilot plants but have not operated on a commercial scale.
- o Third generation are processes which incorporate advanced technology that offers potentially significant advantages to improve process economics. These processes require further development for scaleup to pilot plant demonstrations.

The DOE is sponsoring the development of several of these processes. The objectives of DOE's coal conversion programs are to:

- o Develop and demonstrate in cooperation with industry, new and improved second generation technology required for the construction of commercial scale plants.
- o Identify and accelerate the development of third generation technology to improve process economics on a commercial scale for the 1985-2000 time period.

### 2.1 OPERATIONAL STATUS

Many of the liquefaction processes under development (Figure 2-1) have similar product objectives but have inherent differences in characteristics that require concurrent development support. These differences include reaction conditions, coal pretreatment and method of feed, reactor vessel configuration, product purification, etc. Improvements to present technology

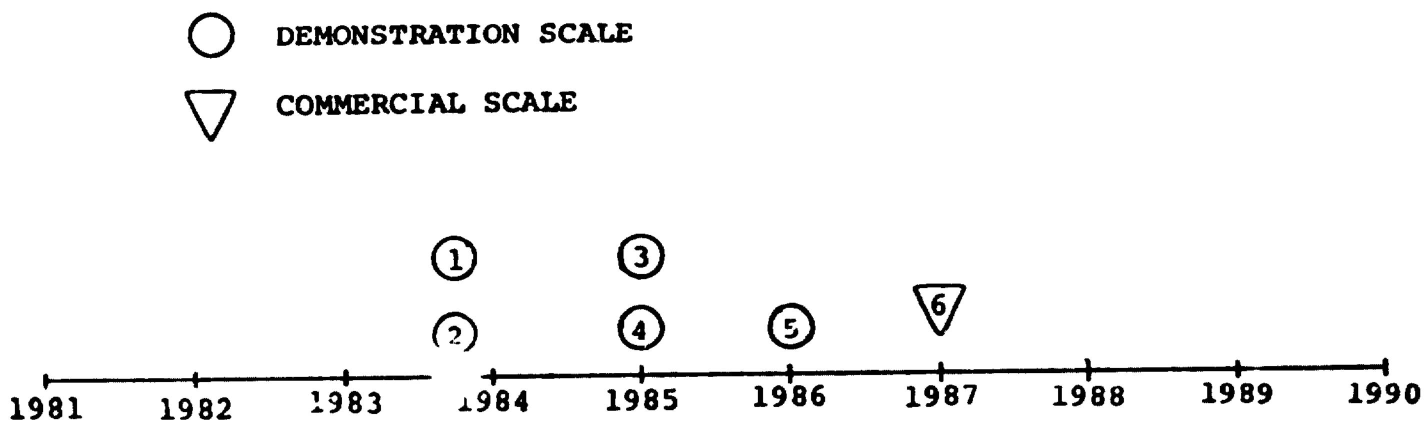
## STATUS OF SYNTHETIC FUELS FROM COAL PROCESSES

| COMMERCIAL PROCESSES | STATUS* | Coal Consumption |
|---|---|---|
| SASOL/Fischer - Tropsch | O | 47,000 TPD |
| | C | 40,000 TPD |
| **DEMONSTRATION PROCESSES** | | |
| SRC-I | D | 6,000 TPD |
| SRC-II | D | 6,000 TPD |
| **LARGE SCALE PILOT PLANTS** | | |
| H-Coal | C | 600 TPD |
| Exxon Donor Solvent | C | 250 TPD |
| **SMALL SCALE PILOT PLANTS** | | |
| Dow Process | O | 2.4 TPD |
| Riser Cracking | O | 1 TPD |
| Zinc Halide | O | 1.1 TPD |
| Flash Liquefaction Process | O | 1 TPH |
| Disposable Catalyst Hydrogenation | O | 0.6 TPD |
| M-Gasoline | D | 25 TPD |

*O-Operational, C-Construction, D-Design, P-Proposed

FIGURE 2-1

# PROCESS DEVELOPMENT SCHEDULE FOR TEST PROGRAM




1 - SRC-I
2 - SRC-II
3 - Exxon Donor Solvent
4 - H-Coal
5 - Dow Liquefaction
6 - Fischer-Tropsch

FIGURE 2-2

is measured primarily in terms of successful operation with eastern U.S. coals and comparative economics and operating costs. DOE's process development and demonstration program is structured to verify the performance of elements, i.e., integrated process streams or modules, of commercial scale plants. The schedule for the major demonstration projects is presented in Figure 2-2.

## 2.2 PROGRAMMATIC STATUS

The programmatic status of the major second generation demonstration projects, the third generation process development activities, and other processes is presented in Figures 2-3 through 2-14. The funding levels shown are those reflected in the DOE FY81 budget submittal to the Congress in January, 1980. Revisions in funding levels have since occurred in some cases.

The size or magnitude differences between the categories of process development and demonstration is not rigid. The categories are differentiated by the kind of information to be obtained and not necessarily by the amounts of raw materials processed. The laboratory bench experimentation confirms key process steps while the PDUs form an integrated small-scale process to test key variables on performance. PDUs generally operate continuously and process the minimum amount of raw material required to test the process feasibility. PDUs are not facilities in themselves, but are a component of, or contained in an existing facility and can undergo considerable modification to enhance the process.

A pilot plant establishes the integrated process feasibility by combining commercial type (not commercial size) into a small model plant to test and evaluate the critical parameters of scaleup, and to acquire engineering data needed to assess economic feasibility and design a larger near-commercial-size plant. Pilot plants are the first scaleup facility to produce enough end-product to permit product testing and refinement and as experimental facilities, are subject to continuing and

## PROGRAMMATIC STATUS

**SRC I**

| | FUNDING: $K FY80 | FY81 |
|---|---|---|
| DEMONSTRATION PLANT: | | |
| OPERATING | 7,000 | 5,000 |
| CONSTRUCTION | 40,000 | 175,000 |
| PILOT PLANT (SRC I & SRC II) | 15,000 | 28,000 |

- SOUTHERN COMPANY SERVICES, EPRI & DOE HAVE SPONSORED A 6 TPD PILOT PLANT OPERATION AT WILSONVILLE, AL.
  - OPERATED BY CATALYTIC, INC. SINCE 1974
  - OBJECTIVE IS TO DEMONSTRATE FEASIBILITY OF CONVERTING HIGH-SULFUR COAL TO CLEAN-BURNING SOLID FUEL
- CONSTRUCTION IS SET TO START IN FY81 ON 6000 TPD DEMONSTRATION PLANT IN NEWMAN, KY; PILOT PLANT SUPPORT OPERATION TO CONTINUE THROUGH FY83 OR BEYOND
- PLANT TO BE FULL SCALE "FIRST MODULE" OF MULTIMODULE COMMERCIAL PLANT WHICH SHOULD
  - PROVIDE A BASIS FOR DETERMINING INVESTMENT AND OPERATIONAL COST FOR COMMERCIAL SCALE
  - DEMONSTRATE TECHNICAL VIABILITY OF PROCESS AND INCREASE INDUSTRY CONFIDENCE IN IMPROVED MATERIALS, DESIGN AND FABRICATION TECHNOLOGIES
  - PROVE ENVIRONMENTAL ACCEPTABILITY OF FUEL PRODUCT

FIGURE 2-3

## SRC I

**PROCESS**

| | | |
|---|---|---|
| DEVELOPER | - | SPENCER CHEMICAL CO. (EARLY 60's) |
| | - | LATER ACQUIRED BY GULF OIL CORP. |
| | - | DEVELOPMENT CONTINUED BY PITTSBURGH & MIDWAY COAL MINING CO. (A GULF SUBSIDIARY) |

**PILOT PLANT** 6 TPD WILSONVILLE, AL (BEGAN OPERATION 1974)

| | | |
|---|---|---|
| DESIGN | - | CATALYTIC, INC. |
| BUILDER | - | CATALYTIC, INC. |
| OPERATOR | - | CATALYTIC, INC. |
| MANAGEMENT | - | SOUTHERN COMPANY SERVICES |
| SPONSORS | - | EPRI, DOE |

**DEMONSTRATION PLANT** 6000 TPD NEWMAN, KY. (OPERATION 1984)

| | | |
|---|---|---|
| CONTRACTOR | - | SOUTHERN COMPANY SERVICES |
| SUB CONTRACTORS | - | AIR PRODUCTS & CHEMICALS, INC.; WHEELABRATOR-FRYE, INC., CATALYTIC, INC. & RUST ENGINEERING CO., INC. |
| SPONSORS | - | DOE |

**RELATED WORK**

- P&M COAL MERRIAM LABORATORY (KANSAS) - SUPPORT PROCESS WORK
- SEVERAL COMPANIES TESTING SRC PRODUCT

FIGURE 2-4

## PROGRAMMATIC STATUS

**SRC II**

| | FUNDING: $K FY80 | FY81 |
|---|---|---|
| DEMONSTRATION PLANT: | | |
| OPERATING | 14,000 | 5,000 |
| CONSTRUCTION | 40,000 | 190,000 |

- 50 TPD PILOT PLANT IN OPERATION AT FT. LEWIS, WA. BY PITTSBURGH AND MIDWAY COAL MINING CO. (SUBSIDIARY OF GULF OIL)
- A MULTIPHASED CONTRACT WAS SIGNED WITH DOE IN 1978 FOR A 6000 TPD DEMONSTRATION PLANT TO BE BUILT NEAR MORGANTOWN, W.V.
  - PLANT WILL BE DESIGNED TO PROCESS PITTSBURGH SEAM COAL INTO CLEAN LIQUID FUEL THAT READILY SUBSTITUTES IN CONVENTIAL LIQUID FUEL TRANSPORTATION AND HANDLING FACILITIES AND BURNS IN OIL FIRED BOILERS WITHOUT MAJOR MODIFICATION
  - CONSTRUCTION START SCHEDULED FOR FY82
- DEMONSTRATION PLANT OBJECTIVES ARE SIMILAR TO THOSE OF SRC I DEMO PLANT

FIGURE 2-5

## SRC II

**PROCESS**

DEVELOPER - SPENCER CHEMICAL CO. (EARLY 60's MODIFICATION OF GERMAN POTT-BROCHE (1920's) PROCESS)

- LATER ACQUIRED BY GULF OIL CORPORATION
- DEVELOPMENT CONTINUED BY PITTSBURG & MIDWAY COAL MINING CO. (P&M COAL) (A SUBSIDIARY OF GULF)

**PILOT PLANT** 50 TPD FT. LEWIS, WA (BEGAN OPERATION 1974)

DESIGN - STEARNS ROGER CORP.

BUILDER - RUST ENGINEERING CO.

OPERATOR - P&M COAL

MANAGEMENT - P&M COAL

SPONSORS - DOE

**DEMONSTRATION PLANT** 6000 TPD MORGANTOWN, WV (OPERATION 1984)

CONTRACTOR - P&M COAL

SUB CONTRACTORS

SPONSORS - DOE, JAPAN, FEDERAL REPUBLIC OF GERMANY

**RELATED WORK**

P&M COAL MERRIAM, KA. LAB. - SUPPORT PROCESS WORK

FIGURE 2-6

## PROGRAMMATIC STATUS

| H-COAL (EBULLATED-BED) | HYDROCARBON RESEARCH, INC. | FUNDING: $K | |
|---|---|---|---|
| | | FY80 | FY81 |
| | | 64,500 | 57,000 |

- o PROCESS CONVERTS HIGH-SULFUR COAL TO EITHER A BOILER FUEL THAT WILL MEET SULFUR EMISSION REGULATIONS OR TO A REFINERY SYNCRUDE.
- o DEVELOPMENT EVALUATIONS SUPPORTED THE TECHNICAL FEASIBILITY OF THE PROCESS IN THE EARLY 1960's.
- o SHAKEDOWN OPERATION OF 600 TPD PILOT PLANT BY ASHLAND SYNTHETIC FUELS BEGAN IN MID 1980 IN CATLETTSBURG, KY
  - DOE IS PROVIDING FUNDS FOR A 3 TPD PROCESS DEVELOPMENT UNIT OPERATION
  - OPERATION OF PILOT PLANT TO EXTEND THRU FY82
- o A COMMERCIALIZATION STUDY IS UNDERWAY AND WILL BE COMPLETED IN FY81; THIS STUDY WILL PRODUCE A CONCEPTUAL DESIGN, COST ESTIMATE, AND A CONSTRUCTION SCHEDULE FOR 20,000 TPD COMMERCIAL PLANT.
  - COAL CHOSEN BY THIS STUDY WILL BE USED FOR PILOT PLANT OPERATION TO VERIFY PRODUCT YIELDS AND CHARACTERISTICS
  - IDENTIFICATION OF AREAS THAT REQUIRE ADDITIONAL DATA FOR DETAILED PLANT DESIGN

FIGURE 2-7

## H-COAL

| | | |
|---|---|---|
| **PROCESS** | | |
| DEVELOPER | - | HYDROCARBON RESEARCH, INC. (TECHNOLOGY ORGINALLY USED IN H-OIL PROCESS) |
| **PROCESS DEVELOPMENT UNIT** | | 3 TPD TRENTON, NJ (BEGAN OPERATION IN MID 1970's) |
| OPERATOR | - | HYDROCARBON RESEARCH, INC. (HRI) |
| **PILOT PLANT** | | 200/600 TPD CATLETTSBURG, KY (BEGAN OPERATION MID 1980) |
| DESIGN | - | HRI |
| BUILDER | - | BADGER PLANTS, INC. |
| SUB CONTRACTOR | - | LUMMUS CO. (DESIGN OF ANTI-SOLVENT DEASHING UNIT) |
| OPERATOR | - | ASHLAND SYNTHETIC |
| MANAGEMENT | - | |
| SPONSORS | - | DOE (80%+), EPRI, ASHLAND OIL CO. STANDARD OIL OF INDIANA, CONOCO COAL DEVELOPMENT CO., MOBIL OIL CO., COMMONWEALTH OF KENTUCKY |

**DEMONSTRATION PLANT**

THERE ARE NO PLANS FOR DEMONSTRATION SCALE PLANT BUT A COMMERCIALIZATION STUDY IS DUE FOR COMPLETION IN FY81 ON A 20,000 TPD DESIGN

FIGURE 2-8

## PROGRAMMATIC STATUS

EXXON DONOR SOLVENT (EDS)

| FUNDING: $K | |
|---|---|
| FY80 | FY81 |
| 30,000 | 32,000 |

- o EXXON RESEARCH AND ENGINEERING INITIATED EDS PROCESS IN 1966 WITH EXXON FUNDING
  - LED TO OPERATION OF 0.5 TPD PILOT PLANT
  - WITH DOE AND INDUSTRY PARTNER FUNDING LABORATORY AND ENGINEERING RESEARCH AND DEVELOPMENT WAS BEGUN IN 1976 ON A 250 TPD PILOT PLANT
- o OPERATION OF THE 250 TPD PILOT PLANT BEGAN IN MID-1980
- o ENGINEERING AND PROCUREMENT BEGAN IN FY80 FOR A 70 TPD PROTOTYPE FLEXICOKER FOR PROCESSING VACUUM TOWER BOTTOMS
- o FY81 OBJECTIVES INCLUDE:
  - COMPLETE PILOT PLANT OPERATIONS ON FIRST BITUMINOUS COAL
  - BEGIN OPERATIONS ON SUB-BITUMINOUS COAL
  - START REVAMP OF PROTOTYPE FLEXICOKER
  - EVALUATE AND IMPROVE PROCESS

**FIGURE 2-9**

## EDS

**PROCESS**

| | | |
|---|---|---|
| DEVELOPER | - | EXXON |
| **PILOT PLANT** | | 250 TPD BAYTOWN, TX. (OPERATION BEGAN 1980) |
| DESIGN | - | ARTHUR G. McKEE & CO. |
| BUILDER | - | DANIEL CONSTRUCTION CO. |
| OPERATOR | - | CARTER OIL CO. (EXXON AFFILIATE) |
| MANAGEMENT | - | EXXON |
| SPONSORS | - | CARTER OIL (23%), EPRI (13%) JAPAN COAL LIQUEFACTION DEVELOPMENT COMPANY (8%)<br>PHILLIPS (2%) ARCO (2%) RUHRKOHLE GERMANY (2%) DOE (50%) |

**DEMONSTRATION PLANT**

EXXON SUCCESS WITH THE LARGE PILOT PLANT WOULD SUPPORT GOING DIRECTLY TO COMMERCIAL SCALE PLANT

FIGURE 2-10

## PROGRAMMATIC STATUS

### DOW LIQUEFACTION PROCESS

- HAS DEVELOPED ITS PROCESS ON A 200 LBS PER DAY LAB SCALE
- PDU IS UNDER CONSIDERATION ON 10 TPD SCALE POSSIBLY IN DOE'S BRUCETON, PA (Synthoil Plant)
- DOW ENVISIONS A 2,000-2,500 TPD DEMONSTRATION SCALE IF THE PDU OPERATION IS SUCCESSFUL

FIGURE 2-11

# PROGRAMMATIC STATUS

## M-GASOLINE

| FUNDING | $K |
|---|---|
| FY80 | FY81 |
| NO DOE FUNDING FOR PROCESS DEVELOPMENT | |

- o EARLY DEVELOPMENT WORK WAS CONDUCTED DURING 1975-76 WITH FUNDING FROM DOE (2 REACTOR FIXED BED SYSTEM)
- o THE FLUID BED REACTOR PROCESS HAS BEEN PROVEN IN A 4 BBL/DAY PILOT PLANT
- o DESIGN OF A 100 BBL/DAY PILOT PLANT HAS BEEN INITIATED AND A 35 BBL/DAY LIQUID PHASE SYNTHESIS GAS CONVERSION PLANT IS BEING PREPARED FOR OPERATION
- o SEVERAL COMMERCIAL OR DEMONSTRATION SCALE PLANTS HAVE REPORTED INTENT TO USE THE M-GASOLINE PROCESS:
  - HAMPSHIRE GROUPS 47,000 BBL/DAY PLANT IN GILLETTE, WY (FUNDED $4 MILLION FOR FEASIBILITY STUDY)
  - W. R. GRACE - 50,000 BBL/DAY - BASKETT, KY
    W. R. GRACE - 10,000 BBL/DAY - COLORADO
  - TENNESSEE ENERGY INSTITUTE - KOPPERS 10,000 BBL/DAY - EASTERN TENNESSEE
  - NEW ZEALAND GOVERNMENT - 12,000 BBL/DAY - NEW ZEALAND

FIGURE 2-12

## THIRD GENERATION PROCESSES

- o ZINC HALIDE (ZINC CHLORIDE CATALYST)
  - CONOCO COAL DEVELOPMENT CO. 100 LB/HR. PDU AT LIBRARY, PA.
  - SUFFICIENT DATA WILL HAVE BEEN COLLECTED IN 1980 TO EVALUATE THE PROCESS
  - PROJECT WILL BE TERMINATED AWAITING EVALUATION
- o DISPOSABLE CATALYST HYDROGENATION
  - PETC (1200 LB/DAY PLANT)
  - GFETC (BENCH SCALE WORK OF REMNANTS OF CO-STEAM PROCESS)
  - P&M COAL CO. MERRIAM, KA. LAB. (25 LBS/DAY BENCH SCALE)
- o SHORT RESIDENCE TIME (SRT) HYDROPYROLYSIS
  - FLASH LIQUEFACTION PROCESS - ROCKWELL INT. (ITPH) PLANT IN CANOGA PARKS, CA. (ROCKWELL & CITIES SERVICE HAVE WORKING AGREEMENT TO JOINTLY ADVANCE PROCESS TO COMMERCIALIZATION)
  - RISER CRACKING PROCESS - IGT - CHICAGO, ILL (100 LB/HR.)
- o TWO-STAGE LIQUEFACTION
  - CE-LUMMUS - PDU, NEW BRUNSWICK, NJ
  - STAGE I IS SRC I, STAGE II IS A DEASHING (UPGRADING) STAGE

FIGURE 2-13

## OTHER PROCESSES

COED - PROVIDES THE CHAR FOR THE "COGAS" GASIFICATION PROCESS, HAS BEEN TESTED IN A 36 TPD PILOT PLANT AT PRINCETON, NJ AND A 50 TPD PILOT PLANT AT LEATHERHEAD, ENGLAND.

CLEAN COKE PROCESS - OBJECTIVE IS TO CONVERT LOW GRADE COAL, TO HIGH GRADE COKE, CHEMICAL FEEDSTOCKS, LIQUID & GASEOUS FUELS;U.S. STEEL HAS DEVELOPED THIS PROCESS TO THE PDU STAGE

TOSCOAL - OIL SHALE CORP. DEVELOPED THIS PROCESS PRIMARILY FOR USE IN OIL SHALE PROCESSING. COAL BEEN PROCESSED IN 25 TPD PILOT PLANT AT GOLDEN, CO. TO PRODUCE CHAR, LIQUID & GAS

SYNTHOIL - DEVELOPED BY PETC AND TESTED IN A 0.5 TPD PILOT PLANT; 10 TPD PILOT PLANT WAS BUILT AT BRUCETON, PA., PLANT IS BEING MAINTAINED IN A STANDBY STATE FOR POSSIBLE USE IN OTHER PROCESS DEVELOPMENT

CONSOL (CFS) - CONSOLIDATED COAL CO. DEVELOPED THIS PROCESS WHICH WAS TESTED IN A 70 TPD PILOT PLANT AT CRESAP, WV; CRESAP FACILITY WAS REMODELED IN 1978 AND WAS PLACED ON STANDBY IN 1980

CLEAN FUEL FROM COAL (CFFC) - CE-LUMMUS HAS DEMONSTRATED THE CFFS PROCESS AT ITS BLOOMFIELD, NJ PILOT PLANT

OCCIDENTAL FLASH PYROLYSIS - OCCIDENTAL RESEARCH CORP. (FORMALLY GARRETT RESEARCH & DEVELOPMENT CO.) TESTED PROCESS IN 3.6 TPD PLANT AT LA VERNE, CA.

FIGURE 2-14

significant modifications to help identify candidate processes and components that could be used for further scaleup to larger plant sizes (engineering phase of RD&D). They are generally limited to 3 years or less of operating life and in most instances are dismantled after fact-finding is complete unless they can be modified to cost effectively test new processes which lead to large pilot plants for some technical development and provide sufficient data about operations and the projected economics and cost of a prospective commercialized plant to allow the development to proceed directly to commercial demonstration.

The purpose of demonstration plants is to demonstrate and validate economic, environmental, and productive capacity of a near commercial-size plant by integrating and operating a single modular unit using commercial-sized components. They are still developmental in the sense that technological scaleup problems may occur and require engineering modification; however, the risk is much lower since the plant production process was developed and tested at the pilot stage. They have a long life and are planned to be expanded to become part of the commercial plant, after their successful demonstration period, by the industrial cost-sharing partner. In this case, the industrial partner will purchase the facilities at a fair market value. They are used only to demonstrate and verify second-generation technologies (those not currently used commercially) and will demonstrate only the most feasible process surviving competition of alternatives regardless of whether previous pilot plant work was done in private industry or government. They are neither formal systems acquisitions nor full-scale development but are the final stage in the R&D process aimed at accelerating and reducing the risks of industrial process implementation.

## 3.0 PROCESS DESCRIPTIONS AND PRODUCTS

### 3.1 SOLVENT REFINED COAL-I (SRC I)

Raw coal is dried and pulverized (90% less than 200 mesh), and blended with a fractionated process derived solvent (boiling range of 249°-454°C, or 480°-850°F). The coal slurry is then pumped under pressure (1500 psig) to the slurry preheater. Prior to entering the preheater, hydrogen-rich recycle gas is injected into the slurry. As this mixture is heated to 750°-800°F in the preheater, dissolution of the coal takes place. The hot slurry then enters the "dissolver", or main reactor vessel, where final conversion to reaction products occurs. Exothermic hydrogenation reactions in the dissolver cause a significant temperature increase (70°F) from the inlet to the outlet, with the outlet temperature normally 850°-870°F.

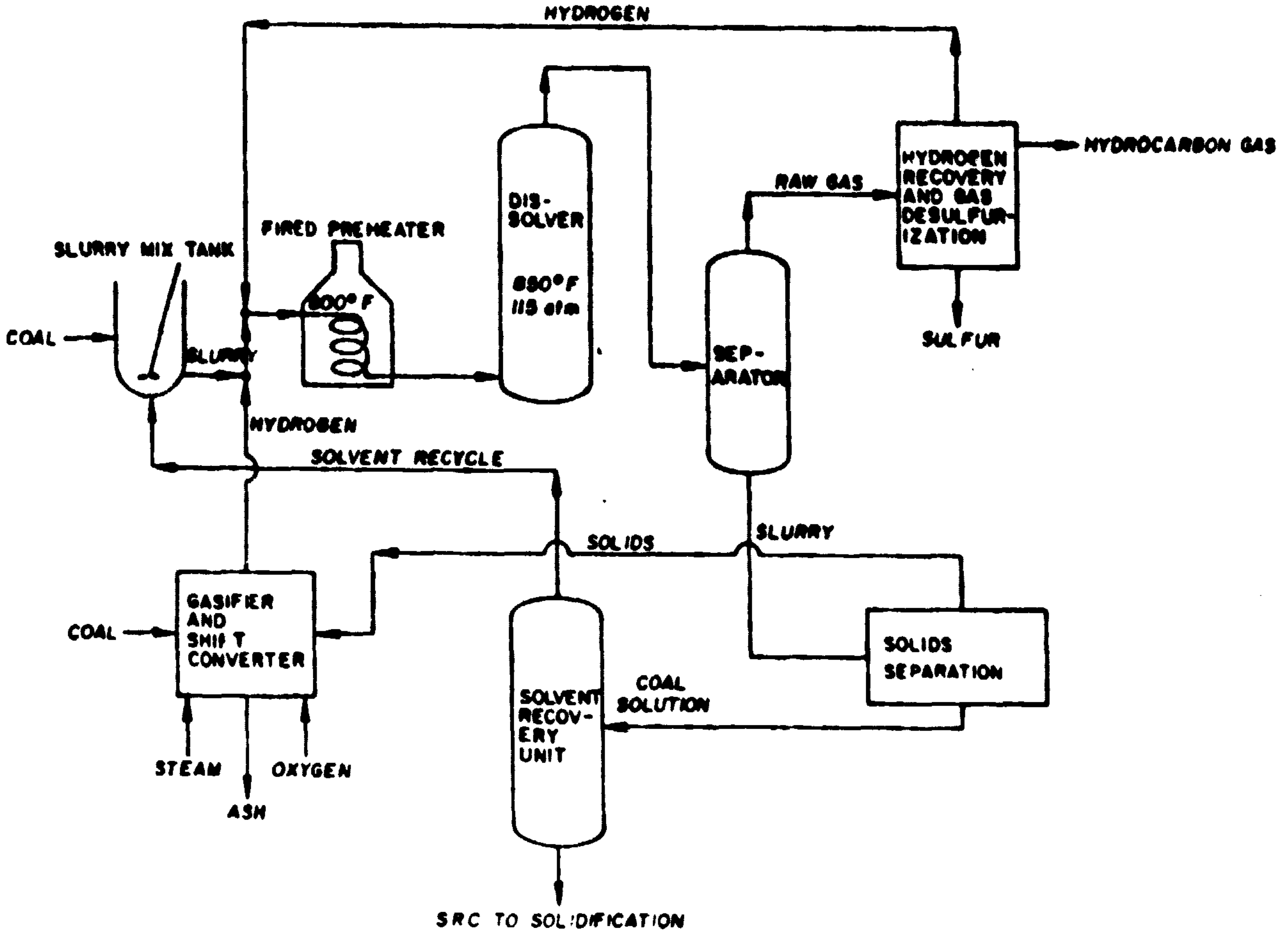
The dissolver effluent is separated into vapor and slurry phases in a series of flash separators, resulting in three major streams: gas (hydrogen, hydrocarbons, and acid gases), liquids (water and distillate hydrocarbon liquids), and slurry (coal solution consisting of both distillable and nondistillable hydrocarbons, unreacted coal, and mineral matter). The gas stream is treated to remove the acid gases, and a portion of the stripped gas is recycled back into the process. The acid gas is further treated to convert hydrogen sulfide to elemental sulfur. The oil recovered from the separator is fed to the solvent fractionation system.

The slurry phase from the separator is fed to either of two rotary pressure precoat filters, where the solids (unreacted coal and mineral matter) are removed from the coal slurry. Filter cake, consisting of the slurry solids and a small quantity of filter precoat (diatomaceous earth) is continuously shaved from the rotating filter drum. The filter cake is then mixed with an intermediate boiling range wash solvent produced in the SRC

process, and the mixture is removed from the filter, and fed to a rotary kiln dryer, where the wash solvent is removed. The resulting dried cake consists of the unreacted coal (insoluble organic matter), the mineral residue, and the pre-coat material.

The filtrate produced during the filtration cycle is preflashed to remove light hydrocarbons, and fed to a vacuum flash system, where the remaining solvent and nondistillate product are separated in a 2.0 psia flash operation. The bottoms fraction from the vacuum flash is SRC and consists of residue which solidifies at about 350°F. The SRC is solidified on a water cooled conveyor belt and stored. The vacuum flash overhead is condensed and fed to the fractionation system.

The fractionation system consists of two columns in which the coal derived liquids are separated into three products: light oil with a boiling range of ambient to 380°F; wash solvent, with a boiling range of 380°-480°F; and process solvent, with a boiling range of 480°F-850°F.




SRC I PROCESS SCHEMATIC

## SRC I

## REACTANTS

Western Kentucky #9 and #14, Wyoming subbituminous, Utah bituminous and Indiana are among the coals that have been processed.

## SAMPLE RUN SRC I PILOT PLANT

## WILSONVILLE, AL.

### COAL SOURCE

| | |
|---|---|
| State | Indiana |
| Seam | V |
| Mine | Old Ben No. 1 |
| Coal Company | Old Ben |
| Rank | High volatile Bituminous |
| Unground Coal, Moisture, wt % | 8.1 |
| Ground Coal Analyses | |
| Proximate Analyses, wt % | |
| Volatile Matter | 36.59 |
| Fixed Carbon | 47.78 |
| Ash | 12.02 |
| Moisture | 3.61 |
| Heating Value, Btu/lb of Coal | 12,472 |
| Ultimate Analyses, wt % dry bases | |
| Carbon | 67.10 |
| Hydrogen | 4.93 |
| Nitrogen | 1.33 |
| Sulfur | 3.99 |
| Ash | 12.47 |
| Oxygen | 10.18 |
| Sulfur Forms, wt % | |
| Pyritic | 1.52 |
| Sulfate | 0.35 |
| Organic | 2.11 |
| Mineral Analyses of Ash, wt % | |
| Sodium oxide, $Na_2O$ | 0.41 |
| Potassium oxide, $K_2O$ | 3.13 |
| Lime, CaO | 4.99 |
| Magnesia, MgO | 0.92 |
| Ferric oxide, $Fe_2O_3$ | 24.49 |
| Titania, $TiO_2$ | 1.07 |
| Phosphorus pentoxide, $P_2O_5$ | 0.02 |
| Silica, $SiO_2$ | 42.16 |
| Alumina, $Al_2O_3$ | 19.66 |
| Sulfur trioxide, $SO_3$ | 2.57 |
| Undetermined | 0.40 |

## SRC I PROCESS

## PRODUCTS

The primary product is a solid coal-like product of less than 1% sulfur and 0.2% ash.

### SAMPLE PRODUCT YIELD

| COAL | ILLINOIS V | |
|---|---|---|
| Basis | Unadjusted | Elementally balanced |
| Yields, % MF coal | | |
| Gas | | |
| $H_2S$ | 3.1 | 2.1 |
| $CO_2$ | 0.8 | 0.6 |
| CO | 0.0 | 0.0 |
| $C_1$ | 1.6 | 1.6 |
| $C_2$ | 1.1 | 1.1 |
| $C_3$ | 1.1 | 1.2 |
| $C_4$-$C_5$ | 0.7 | 0.7 |
| Water | 4.6 | 3.4 |
| Distillates | | |
| $C_5$-350°F | 2.5 | 2.7 |
| 350-450°F | 3.2 | 3.8 |
| 450-950°F | 9.2 | 13.3 |
| SRC | 57.5 | 56.4 |
| Ash | 10.7 | 10.0 |
| Unreacted coal | 6.2 | 5.9 |
| Hydrogen consumption, % MF coal | 2.5 | 2.7 |

## 3.2 SOLVENT REFINED COAL-II (SRC II)

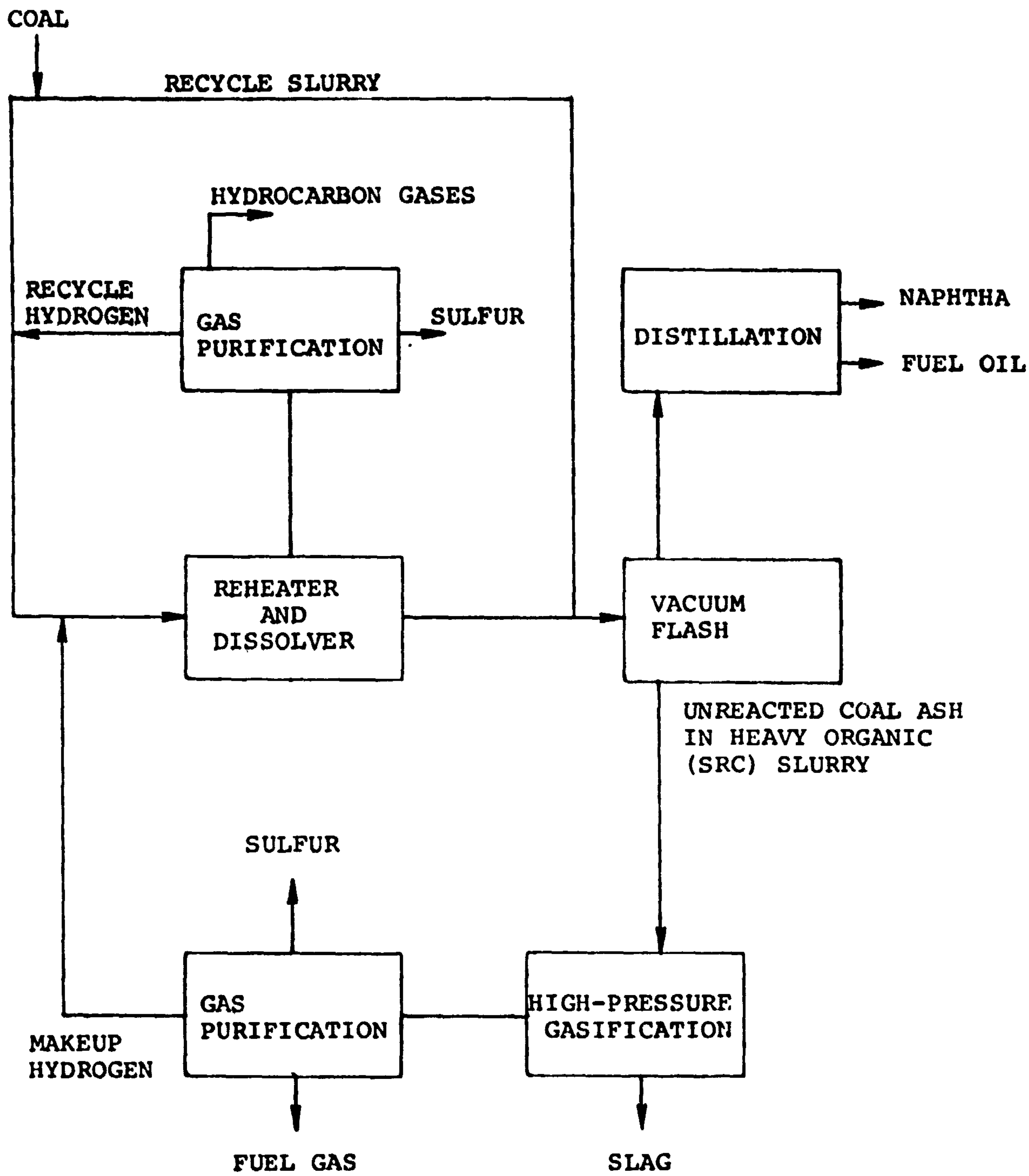
Dried pulverized coal is blended with stripped dissolver effluent slurry (recycle slurry) and pumped into the slurry preheater. Prior to entering the preheater, the slurry is combined with a hydrogen-rich gas stream. The preheater effluent passes through the dissolver and into the dissolver effluent separators where gas and light hydrocarbon liquids are separated from the slurry. The slurry is stripped with inert gas to further decrease the concentration of light hydrocarbon liquids, and is then split into two streams, one returning to the coal blending area, and the other passing into a vacuum flash unit. The vacuum flash condensate is fed to the fractionation system. The vacuum bottoms stream containing SRC (distillation residue with a 850°F+ boiling range), unreacted coal, and coal mineral matter is solidified and stored. This vacuum material would commercially be used to generate hydrogen gas for the process in a gasification unit.

All of the liquid hydrocarbon products from the coal are combined and fractionated to produce three liquid products: "naptha", with a boiling range of 350°F; "middle distillate", with a boiling range of 350°F to 550°F; and "heavy distillate", with a boiling range of 550°F to 850°F. Hydrocarbon gases ($C_1$-$C_4$), carbon monoxide, carbon dioxide, ammonia, water, and hydrogen sulfide are also produced.

The recycle of product slurry in the SRC II operating mode results in a more complete conversion of high molecular weight material into distillate products than is possible by blending coal solely with recycle solvent. By choosing the appropriate amount of recycle slurry and other reaction area operating parameters, it is possible to decrease the yield of SRC to 20-30% of the moisture-free coal feed. This reduced SRC yield is complemented by increased yields of middle and

heavy distillate and a higher hydrocarbon gas yield than would be experienced without slurry recycle. The change in product distribution to lighter products coincides with a higher hydrogen consumption (4-5% of the coal feed) compared to SRC I operation (2% of coal feed). The only other significant difference in reaction conditions between the SRC I and SRC II processing modes are the higher dissolver pressures utilized in SRC II (1900 psig vs 1500 psig in SRC I), and the lower feed slurry rates and higher dissolver volume in the SRC II mode, which result in a twofold to fourfold increase in the superficial slurry residence time in the dissolver.

The increased conversion of SRC to distillate products in the SRC II mode results from: the increased concentration of SRC at the dissolver inlet where hydrogen partial pressure is greatest; the increased dissolver concentration of mineral matter which acts as a catalyst; the increased single pass dissolver residence time (due to increased dissolver volume and lower slurry feed rates); and, the increased multiple pass residence time due to the use of recycle slurry for coal blending.




SRC-II PROCESS SCHEMATIC

## SRC II PROCESS

## REACTANTS

### COMPARISON OF SRC II DEHUMIDIFIED FEED COAL

SRC II PILOT PLANT - FT. LEWIS, WA.

| | W. Ky. | Ill. #6 | Pitt Seam |
|---|---|---|---|
| **Proximate Analysis, wt %** | | | |
| Moisture | 2.04 | 2.79 | 1.55 |
| Ash | 10.12 | 12.41 | 12.16 |
| Volatile Matter | 36.68 | 37.48 | 34.89 |
| Fixed Carbon (by difference) | 51.16 | 47.32 | 51.40 |
| Btu/lb (dry basis) | 13068 | 12215 | 13251 |
| kcal/gm (dry basis) | 7.26 | 6.79 | 7.37 |
| % Sulfur (dry basis) | 3.39 | 3.70 | 2.62 |
| **Sulfur Forms, wt %** | | | |
| Pyritic (dry basis) | 1.49 | 1.15 | 1.38 |
| Sulfate (dry basis) | 0.11 | 0.26 | 0.03 |
| Organic (by difference) | 1.79 | 2.29 | 1.21 |
| **Ultimate Analysis wt % (dry basis)** | | | |
| Carbon | 71.89 | 67.89 | 73.79 |
| Hydrogen | 5.04 | 4.93 | 5.05 |
| Nitrogen | 0.63 | 1.07 | 0.91 |
| Chlorine | 0.06 | 0.04 | 0.10 |
| Sulfur | 3.39 | 3.70 | 2.62 |
| Ash | 10.33 | 12.77 | 12.35 |
| Oxygen (by difference) | 8.66 | 9.60 | 5.18 |
| $Fe_2O_3$ in Ash, wt % | 21.68 | 16.65 | 17.29 |

## PRODUCTS

The primary products are low sulfur fuel oil and naphtha.

### SRC-II PRODUCT YIELDS

| COAL | W. Ky. | Ill, #6 | Pitt Seam |
|---|---|---|---|
| Dehumidified Coal Feed Rate, #/hr. | 1984 | 2008 | 1998 |
| kg/hr. | 900 | 911 | 906 |
| Feed Slurry Composition, wt % | | | |
| Deh. Coal | 29.5 | 29.5 | 30.3 |
| Solvent | 33.4 | 35.6 | 29.8 |
| SRC | 23.9 | 20.0 | 24.1 |
| Ash (due to recycle slurry) | 8.2 | 11.0 | 8.3 |
| IOM (due to recycle slurry) | 5.0 | 3.9 | 7.5 |
| Nominal Dissolver Residence Time, Hrs. | 0.98 | 0.97 | 1.00 |
| Hydrogen Purity in Feed Gas, Mole % | 89.8 | 93.7 | 91.6 |
| Average Dissolver Temperature, °C | 461 | 457 | 456 |
| °F | 861 | 854 | 853 |
| Dissolver Pressure, MPa | 13.34 | 13.44 | 14.09 |
| psig | 1920 | 1934 | 2029 |
| Yields, wt % M.A.F. Coal | | | |
| Hydrogen Consumption | -4.8 | -4.7 | -3.5 |
| Hydrocarbon Gas ($C_1$ to $C_4$) | 18.4 | 15.8 | 13.5 |
| Naphtha | 14.2 | 17.0 | 11.9 |
| Middle Distillate + Heavy Distillate | 28.2 | 30.3 | 22.3 |
| SRC | 26.1 | 23.0 | 36.8 |
| IOM (unreacted coal) | 6.6 | 5.0 | 11.9 |

### 3.3 H-COAL

The H-Coal process is a catalytic hydroliquefaction process that converts high-sulfur coal to either a boiler fuel that will meet sulfur emission regulations or to a refinery syncrude.

Coal is dried, pulverized, and slurried with coal-derived oil for charging to the coal hydrogenation unit. The heart of the process is the reactor design. The coal-oil slurry is charged continuously with hydrogen to a reactor containing a bed of ebullated catalyst wherein the coal is catalytically hydrogenated and converted to liquid and gaseous products. In the ebullated bed the upward passage of the solid, liquid, and gaseous materials maintains the catalyst in a fluidized state. The relative size of the catalyst and coal is such that only the unconverted coal, ash, liquid and gaseous products leave the reactor while retaining the catalyst therein. Catalyst can be added and withdrawn continuously so a constant activity can be maintained. The reactor provides a simple means of controlling reactor temperature (typically 650°-700°F entering the reactor) and an effective contact between reacting species and the catalyst, permitting a satisfactory degree of reaction at reasonable operating pressures.

The gas and liquid products (hydrocarbons gas, hydrogen sulfide, ammonia, light and heavy distillates, and residual fuel) may be further refined as necessary. Heavy distillate is recycled as the slurry medium. In the commercial configuration, the vacuum bottoms stream containing unreacted carbon and some liquid will eventually be processed onsite to produce hydrogen needed for the process. In the H-Coal pilot plant, hydrogen will be supplied by the adjacent Ashland Oil Refinery.

The vapor product leaving the top of the reactor is cooled to condense the heavier components as a liquid. Light hydrocarbons, ammonia and hydrogen sulfide, are absorbed and separated

from the remaining gas, leaving a hydrogen-rich gas which is recompressed and recycled to be combined with the input slurry. The liquid-solid product, containing unconverted coal, ash, and oil, is fed into a flash separator. The material that boils off is passed to an atmospheric distillation unit. The bottoms product containing solids and heavy oil is further separated with a hydroclone, a liquid-solid separation, and a vacuum still.

## H-COAL

### REACTANTS

COAL:

This process will operate on almost any type of coal. Illinois No. 6 and Wyodak coals have to be tested over a sufficiently wide range of conditions so that operating conditions and yields for any desired product slate can be predicted.

COAL ANALYSIS (AS-RECEIVED)

| | Illinois No.6 | Wyodak |
|---|---|---|
| Moisture, W % | 17.5 | 30.4 |
| Proximate Analysis, W % (Dry Basis) | | |
| Ash | 9.9 | 7.9 |
| Volatile Matter | 42.0 | 44.1 |
| Fixed Carbon | 48.0 | 48.1 |
| Ultimate Analysis | | |
| Carbon | 70.7 | 68.4 |
| Hydrogen | 5.4 | 5.4 |
| Nitrogen | 1.0 | 0.8 |
| Sulfur | 5.0 | 0.7 |
| Oxygen (Difference) | 8.1 | 16.9 |
| Ash | 9.9 | 7.9 |

## H-COAL

## REACTANTS (cont'd)

### HYDROGEN:

Before the H-Coal process can become commercially and economically competitive, an adequate supply of hydrogen must be generated from the process itself. The process requirements are between 14,000 and 20,000 SCF per ton of coal processed.

### CATALYST:

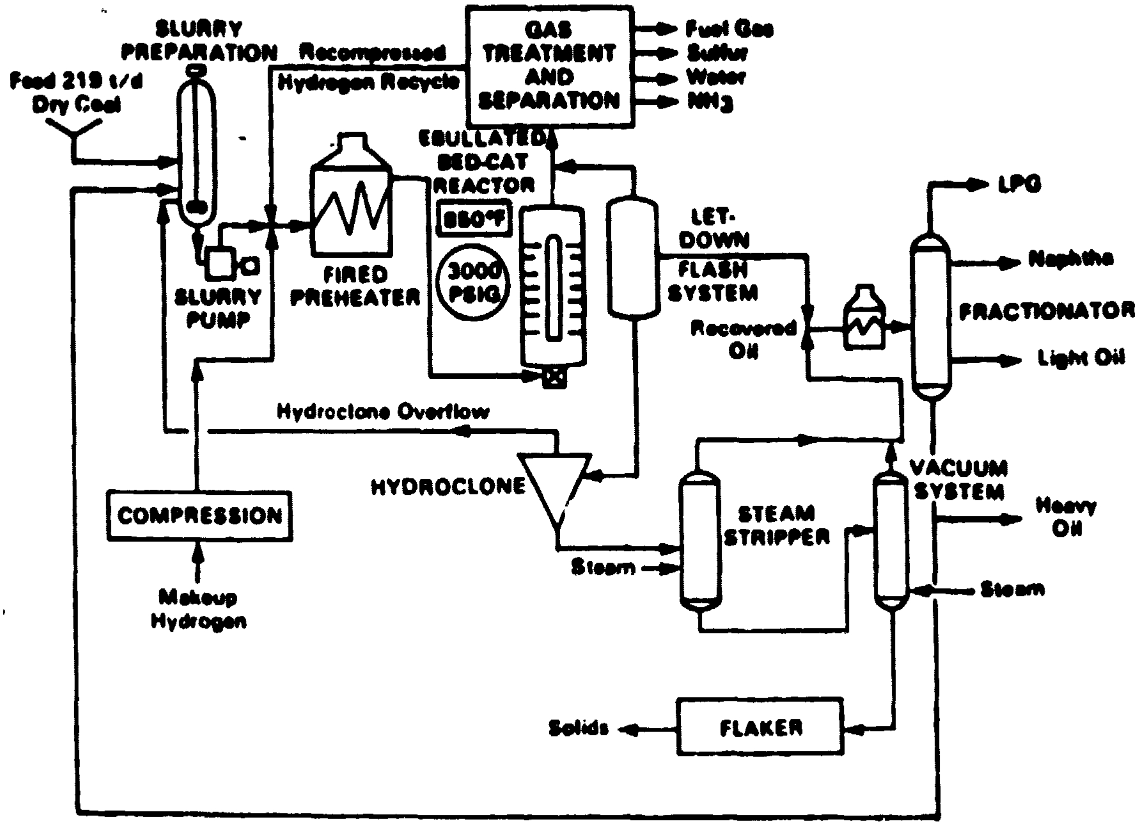
Approximately 4.2 lbs of recharge catalyst is required per ton of coal. Typical catalysts have been CO,Ni or MO on a porous particulate support (activated alumina).

## PRODUCTS

Operation of a 250-600 TPD Pilot Plant Operation began in mid 1980 at Catlettsburg, KY. When this facility is operated at 250 T/D the net product is all distillate (syncrude) material. Increasing throughput to 600 T/D changes the major product to a heavy #6 fuel oil type material. This operation requires a solid separation step. Lummus Anti-solvent Deashing was selected for this purpose.

# TYPICAL H-COAL PROCESS YIELDS

| COAL | Illinois | | Wyodak |
|---|---|---|---|
| Desired Product | Synthetic Crude | Low-Sulfur Fuel Oil | Synthetic Crude |
| **Normalized Product Distribution** | | | |
| $C_1$-$C_3$ Hydrocarbons | 10.7 | 5.4 | 10.2 |
| $C_4$-400°F Distillate | 17.2 | 12.1 | 26.1 |
| 400-650°F Distillate | 28.2 | 19.3 | 19.8 |
| 650-975°F Distillate | 18.6 | 17.3 | 6.5 |
| 975°F + Residual Oil | 10.0 | 29.5 | 11.1 |
| Unreacted Ash-Free Coal | 5.2 | 6.8 | 9.8 |
| $H_2O$, $NH_3$, $H_2S$, $CO$, $CO_2$ | 15.0 | 12.8 | 22.7 |
| Total (100.0 + $H_2$ Reacted) | 104.9 | 103.2 | 106.2 |
| Conversion % | 94.8 | 93.2 | 90.2 |
| Hydrogen Consumption, SCF/Ton | 18,600 | 12,200 | 23,600 |




H-COAL PROCESS, SYNCRUDE MODE

## 3.4 EXXON DONOR SOLVENT (EDS)

Coal is ground and slurried with the recycle donor solvent. The slurry is heated by a fired heater, and preheated gaseous hydrogen is added. The reaction is carried out in a tubular reactor with no internals. Products from the liquefaction reactor are sent to several stages of separation units for recovery of gas, naphtha, middle distillate, and bottoms comprised primarily of unreacted coal and mineral matter. Distillation is the means for solid-liquid product separation.

The heavy bottoms from distillation are sent to a FLEXICOKER to produce additional liquids and low-Btu gas for in-plant fuel use. Hydrogen for in-plant use is provided by steam reforming of $C_1$-$C_2$ gases produced in the process or by partial oxidation. The hydrogen is recycled to the liquefaction and solvent hydrogenation sections.

A portion of the middle distillate product is sent to the solvent hydrogenation step, using a catalytic fixed-bed reactor to produce donor solvent to be recycled to the slurry preparation step. Depending on the ultimate produce utilization, the primary liquid products may be further refined.

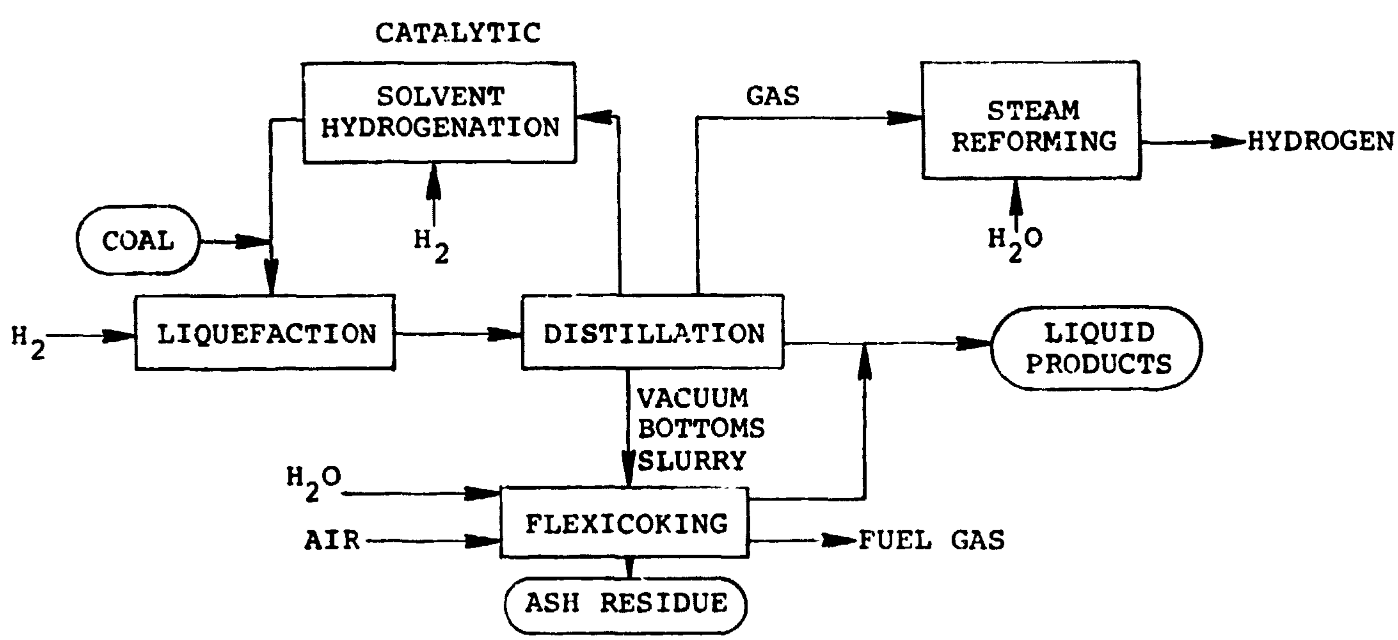
The plant is balanced in that it is self-sufficient in both process fuel and $H_2$ requirements. The process gives high yields of low-sulfur liquids from bituminous coal, sub-bituminous coal or lignites. For Illinois bituminous coal, the liquid yield is determined to be 2.8 barrels of $C_4$/1000°F liquids per ton of dry coal feed.

### REACTANTS

The plant is "balanced" in that it is self-sufficient in both process fuel and hydrogen requirements. Process fuel

and hydrogen are produced by gasifying the coke and by reforming $C_1$-$C_2$ gases from the liquefaction process.

The noncatalytic liquefaction step is separated from the catalytic hydrogenation step. As a result, the hydrogenation catalyst is exposed to only distillate coal liquids. This results in very low catalyst deactivation rates and also allows direct control of the amount of hydrogen actually added to the coal through the donor solvent.




DONOR SOLVENT LIQUEFACTION PROCESS SCHEMATIC

EDS

PRODUCTS

Process conditions may be varied to change the product slate. The following table shows the results of studies by EXXON on product utilization.

EDS LIQUID YEILD DISTRIBUTION AND POTENTIAL APPLICATIONS

- Illinois No. 6 Coal (Monterey)
- Base Liquid Yield = 45 wt. % Dry Coal

| PRODUCT BOILING RANGE | PRODUCT DISTRIBUTION % TOTAL LIQUID BASE | PRODUCT DISTRIBUTION % TOTAL LIQUID RANGE | POTENTIAL APPLICATION |
|---|---|---|---|
| $C_4$ - 350°F | 37 | (25-55) | Motor Gasoline Blend Stock After Hydrotreating/Reforming |
| 350/650°F | 24 | (10-25) | Distillate Fuel Oil Or Heavy Fuel Oil |
| 650°F$^+$ | 39 | (35-50) | Heavy Fuel Oil |

## 3.5 MOBIL M-GASOLINE PROCESS

Process Development studies have been conducted on both fixed and fluid bed plants.

The fixed bed process consist of two reactors in series. The first reactor (dehydration reactor) is a long slender vessel in which the methanol charge is converted to an equilibrium mixture of methanol, dimethylether, and water. About 20% of the total heat load for methanol to gasoline is released in this reactor.

The products from the first reactor are mixed with recycle gas, and the mixture is passed over the conversion catalyst in the second reactor (conversion reactor), where the formation of hydrocarbons occurred.

The products from the conversion reactor are cooled and flashed in a high pressure separator. Aqueous and organic liquid phases are withdrawn continuously from the separator and depressured to atmospheric pressure.

The liquid phases are collected in a product receiver, and the heavy gas product is mixed with unit purge gas. The gaseous material from the separator is heated above its dew point,demisted, and sent to heated compressors for circulation to the conversion reactor.

The fluid bed process has been verified in a pilot plant capable of converting 4 barrels per day of methanol into hydrocarbons and water.

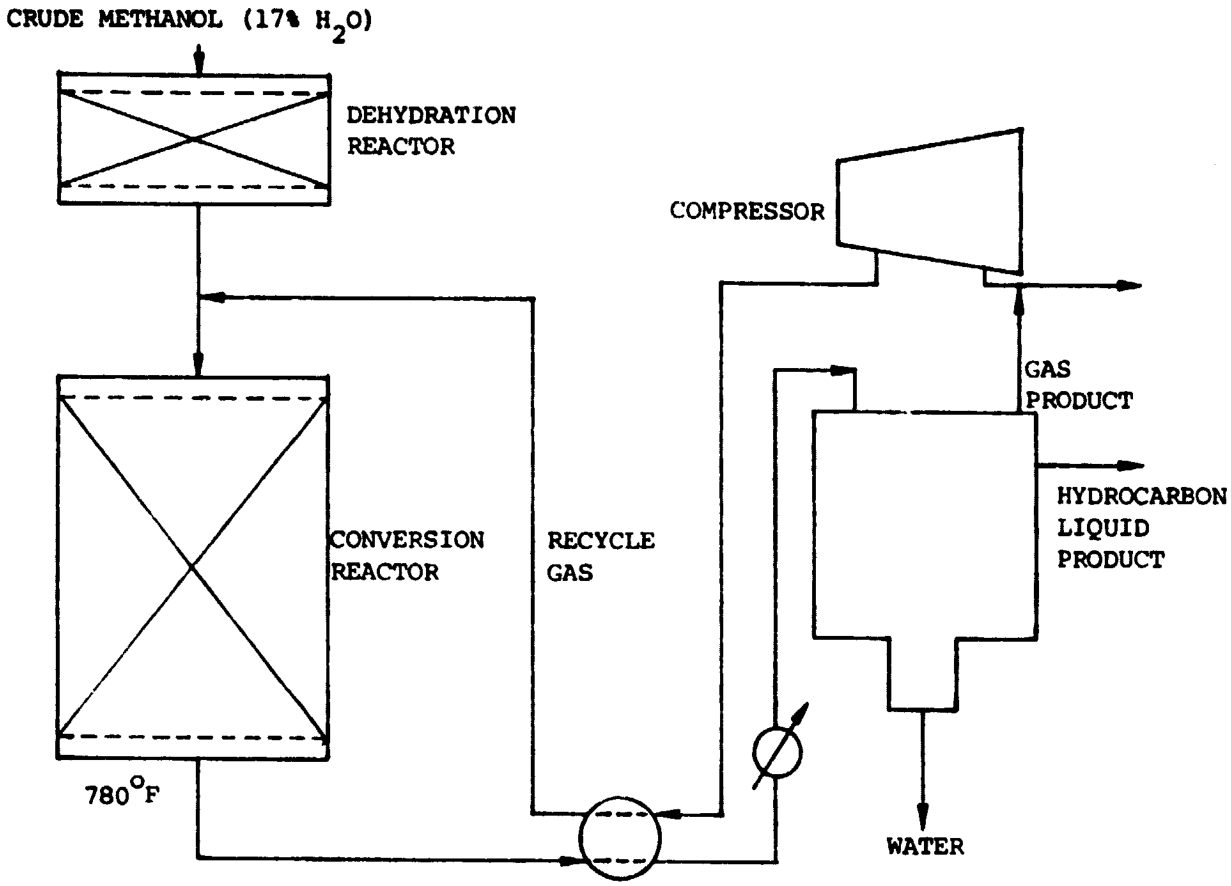
The reactor is 4 inches inside diameter and 25 feet high, and is complete with recirculating and regeneration facilities. The pilot plant simulates a vertical element of a heavily baffled commercial size reactor where the effective hydraulic radius is reduced to several inches due to internal baffling.

The reactor is equipped with cooling jackets and access ports for thermocouple insertion, emergency flooding with $N_2$, intermediate product sampling, and capacitance probe insertion. Six adiabatic zone heaters maintain a zero temperature differential between the heaters and the reactor surface to prevent reactor heat losses. Methanol is fed into the bottom of the reactor by means of a distributor.

The product and catalyst mixture passes into a disengager (16" ID x 36" high) where the entrained catalyst is separated from the product, collected and returned to the bottom of the reactor via a 2½" ID external catalyst recirculation line. Fluidizing nitrogen is introduced at the slanting face of the conical section to promote catalyst movement and recirculation. The disengager is heated to approximately 600°F to prevent product condensation.

Catalyst is regenerated isothermally in a batch mode at a rate of 10% of the reactor catalyst inventory per day. Catalyst transfer between the reactor and regenerator is controlled by maintaining a constant differential pressure between the two vessels. The catalyst flow rate is measured by means of a calibrated orifice in the transfer line. The regeneration is controlled by regulating the amount of oxygen supplied.

The product stream from the disengager is filtered and passed through a three-stage condenser. Service water is used for cooling in the first and second stages while refrigerated glycol is used for the third stage. The light gas for recycle is withdrawn from the first stage. The effluent from the third stage is separated into gases, hydrocarbon liquid, and water.




MOBIL M-GASOLINE PROCESS SCHEMATIC

MOBIL M-GASOLINE

REACTANTS

Methanol from a gasification process is fed to M-Gasoline process to produce gasoline by indirect liquefaction.

CATALYSTS:

Catalyst (zeolite - ZSM-5 class) is added as regeneration to the process at a rate of about 10% of the catalyst inventory per day.

MOBIL M-GASOLINE

TYPICAL YIELDS FROM METHANOL

| | |
|---|---|
| Average Bed Temperature, °F | 775°F |
| Pressure, psig | 25 |
| **Yields, Wt % of Methanol Charge** | |
| Methanol + Ether | 0.2 |
| Hydrocarbons | 43.5 |
| Water | 56.0 |
| CO, $CO_2$ | 0.1 |
| Coke, Other | 0.2 |
| | 100.0 |
| **Hydrocarbon Product, Wt %** | |
| Light Gas | 5.6 |
| Propane | 5.9 |
| Propylene | 5.0 |
| i-Butane | 14.5 |
| n-Butane | 1.7 |
| Butenes | 7.3 |
| $C_5$ + Gasoline | 60.0 |
| | 100.0 |
| Gasoline (including Alkylate) (96.8 Unleaded Research Octane) | 88.0 |
| LP Gas | 6.4 |
| Fuel Gas | 5.6 |
| | 100.0 |

## MOBIL M-GASOLINE

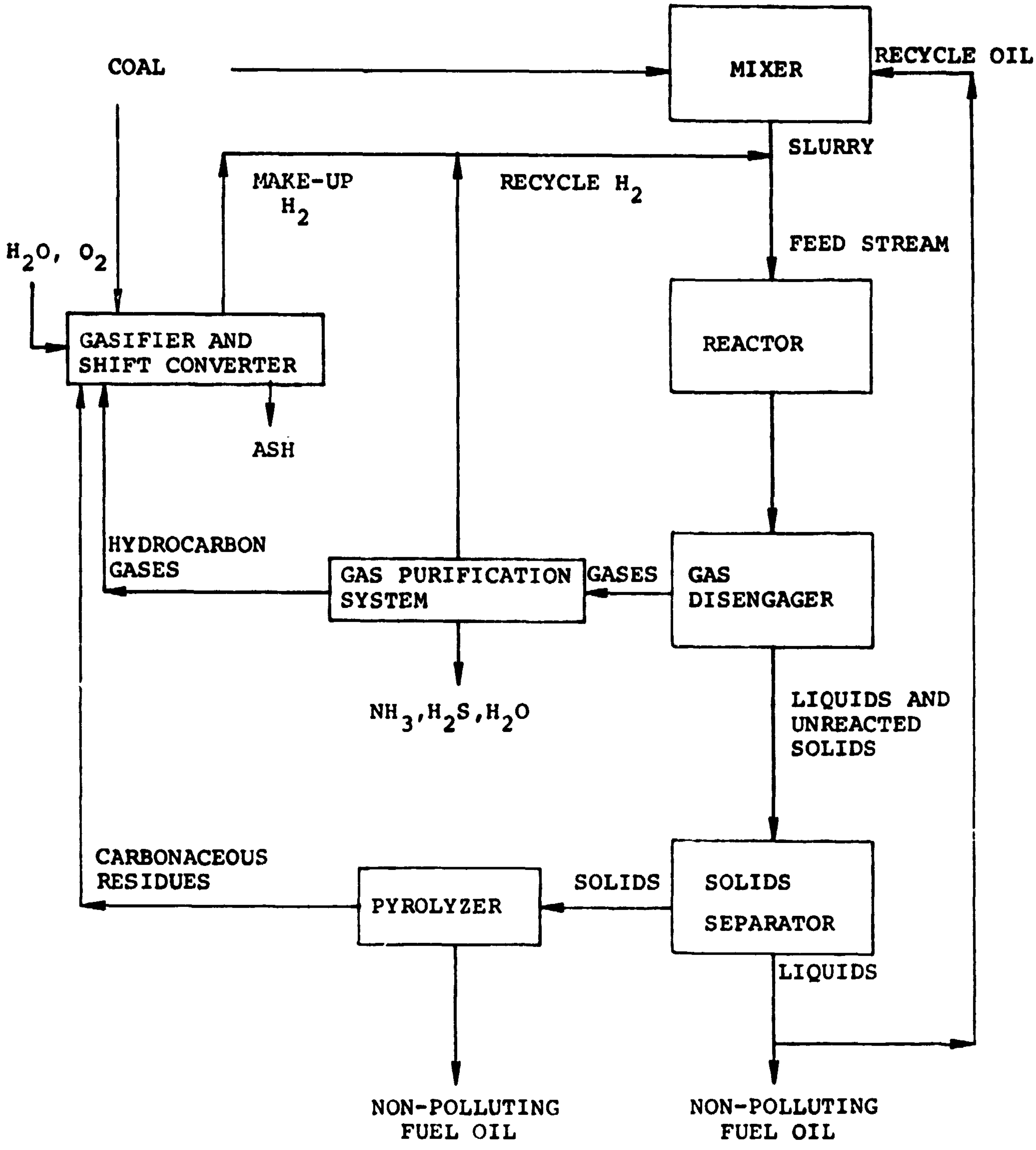
## TYPICAL PROPERTIES OF FINISHED GASOLINE

| Components, Wt % | | |
|---|---|---|
| Butanes | 3.2 | |
| Alkylate | 28.6 | |
| $C_5$ + Wt % | 68.2 | |
| | 100.0 | |
| **Composition, Wt %** | | |
| Paraffins | 56 | |
| Olefins | 7 | |
| Naphthenes | 4 | |
| Aromatics | 33 | |
| | 100 | |
| **Octane** | **Research** | **Motor** |
| Clear | 96.8 | 87.4 |
| Leaded (3 cc TEL/US Gal) | 102.6 | 95.8 |
| Reid Vapor Pressure, psi | 9.0 | |
| Specific Gravity | 0.730 | |
| Sulfur, Wt. % | Nil | |
| Nitrogen, Wt % | Nil | |
| Durene, Wt % | 3.8 | |
| Corrosion, Copper Strip | 1A | |
| **ASTM Distillation, °F** | | |
| 10% | 117 | |
| 30% | 159 | |
| 50% | 217 | |
| 90% | 337 | |

## 3.6 SYNTHOL PROCESS

Hydrogen and a slurry of powdered coal in a portion of the product oil are introduced concurrently into a reactor packed with pellets of a commercial hydrodesulfurization catalyst or inert pellets. The product stream flows into a gas disengager where the liquid and unreacted solids are separated from the gases. The liquid stream is passed through a solids separator to remove the unreacted solids consisting of mineral matter and refractory coal substance. The liquid product is a nonpolluting fuel oil.

Gases from the disengager are led through a purification train to remove $NH_3$, $H_2S$, $H_2O$, and most of the gaseous hydrocarbons. The remainder consisting of unconsumed $H_2$ and a small amount of hydrocarbon gases is recycled to the reactor. Solids from the solids separator go to a pyrolyzer which yields an additional quantity of nonpolluting fuel oil and a carbonaceous residue consisting mostly of mineral matter. This residue, together with the gaseous hydrocarbons from the gas purification system, is fed to a gasifier to produce $H_2$ for the process. Some coal may also be added to the gasifier if additional $H_2$ is needed. Ash from the gasifier may be disposed of as mine fill while the $NH_3$ and $H_2S$ (after conversion to elemental S) would be useful byproducts.




SYNTHOL PROCESS SCHEMATIC

SYNTHOIL PROCESS

REACTANTS

CATALYST

Research has indicated that the process will operate with inert pellets replacing the catalyst, therefore a catalyst ($Co-Mo/SiO_2-Al_2O_3$) may or may not be used.

COAL

ANALYSIS OF FEED COAL, AS RECEIVED

| Coal | Kentucky | West Va. |
|---|---|---|
| Proximate Analysis, Wt Pct | | |
| Moisture ......... | 4.2 | 1.6 |
| Ash .............. | 16.5 | 8.1 |
| Volatile matter .. | 36.2 | 41.6 |
| Fixed carbon ..... | 43.1 | 48.7 |
| Ultimate Analysis, Wt. Pct | | |
| Hydrogen ........ | 4.8 | 5.3 |
| Carbon .......... | 60.7 | 73.8 |
| Nitrogen ........ | 1.2 | 1.4 |
| Oxygen .......... | 11.3 | 7.6 |
| Sulfur .......... | 5.5 | 3.8 |
| Ash ............. | 16.5 | 8.1 |
| Form of Sulfur, Wt. Pct | | |
| Sulfate ........ | 0.47 | 0.09 |
| Pyritic ........ | 3.08 | 1.79 |
| Organic ........ | 1.95 | 1.92 |
| Calorific value, Btu/lb ............ | 11,020 | 13,400 |
| Free swelling index . | 5 | 8 |

## EXAMPLE SYNTHOIL OPERATIONS

Reactor: 1.1-inch ID x 14.5 ft. long
Charge weight of Co-Mo/$SiO_2$-$Al_2O_3$ catalyst: 5.5 lb
Reactor temperature: 450° C
Preheater: 3-inch ID x 11 ft. long
Preheater packing: 3/4-inch x 3/4-inch ceramic pellets
slurry compositions: 35 coal + 65 recycle oil
Slurry feed rate: 25 lb/hr
Gas recycle rate: 1,000 scfh
Makeup $H_2$ feed rate: 300 scfh

| | | | |
|---|---|---|---|
| Preheater outlet temperature, °C ... | 450 | 430 | 430 |
| S in product oil, wt pct ........... | 0.2 | 0.45 | 0.5-0.7 |
| Ash in product oil, wt pct .......... | 0.1-0.2 | 0.75 | 1.3-2.9 |
| Viscosity of product oil, SSF ...... | 26-440 | 10-30 | 14-98 |
| Specific gravity of product oil, 60°F/60°F ........................ | 1.020-1.082 | 1.034-1.094 | 1.060-1.148 |
| Calorific value of product oil, Btu/lb ........................... | 17,400 | 17,800 | 16,640 |
| Yield of product oil, bbl/ton of coal (as received) ............... | 3.3 | 3.2 | 3.0 |
| Consumption of $H_2$, scf/bbl of product oil ...................... | 4,375 | 4,170 | 3,450 |

### 3.7 SHORT RESIDENCE TIME HYDROPYROLYSIS (SRT) (FLASH LIQUEFACTION & RISER CRACKING)

Research and development of short residence time (SRT) pyrolysis of coal hydrogen (hydropyrolysis) is currently proceeding on a broad front both fundamentally at universities and national laboratories and on a more applied basis at Rockwell, Cities Service, and the Institute of Gas Technology (IGT).

FLASH LIQUEFACTION PROCESS DESCRIPTION

The basic concept of this process for the partial liquefaction of coal is that high liquid yields are favored by rapid mixing, reaction, and quenching of pulverized coal and hot gaseous hydrogen. In this process, as shown in the flow diagram, coal is fed into the reactor from a batch feeder by pressurizing the holding tank without aerating the coal. In the reactor the pulverized coal is entrained rapidly with 2000°F hydrogen using a rocket engine injector element. There they react for about 10 to 100 milli-seconds at a pressure between 35 and 100 atmospheres and a temperature of 1500 to 1800°F.

The reactor effluent is quenched, utilizing a set of water spray nozzles or a heat exchanger, or both. From there, the residual char is collected by cyclone, and the liquids are condensed.

RISER CRACKING PROCESS DESCRIPTION

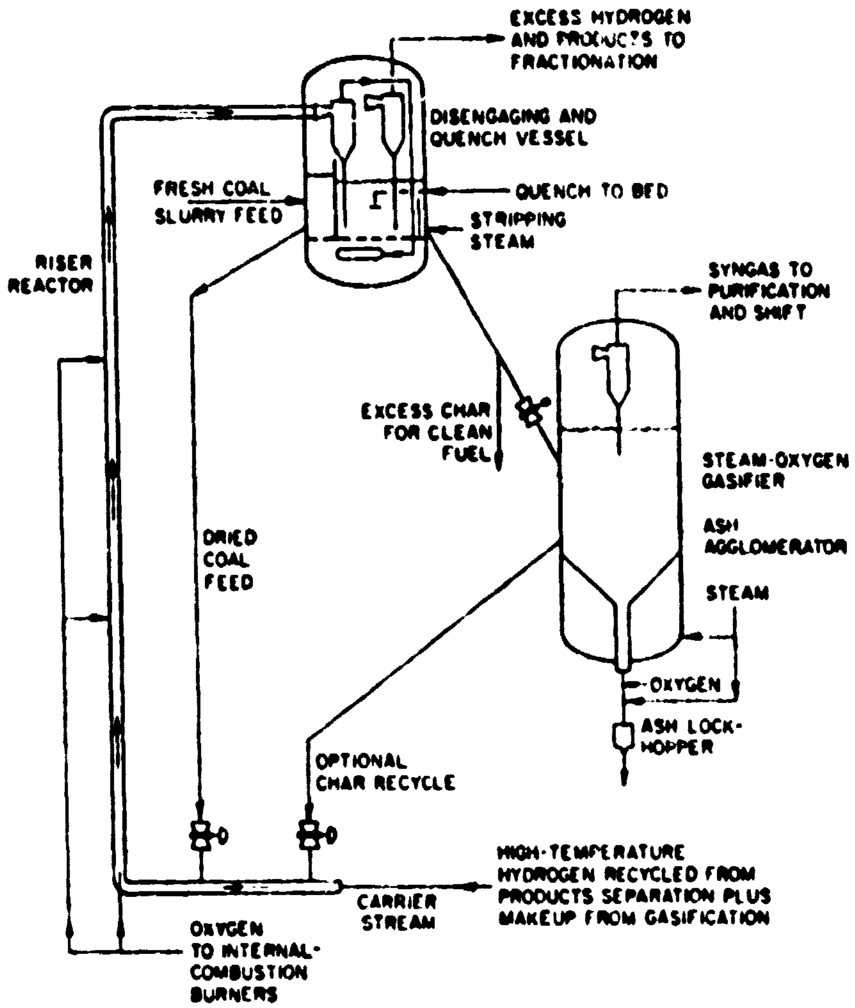
Heated hydrogen and coal (about 1200°F) are fed to the riser reactor traveling concurrently upwards before entering the disengaging vessel to separate unreacted char from the hydrogen carrier and product vapors by means of a pair of cyclones. A quench oil derived from the process is sprayed into the char bed to lower the reactor effluent temperature and stop the pyrolysis reactions. Reaction heat is supplied in stages by means of oxygen-hydrogen combustion internally within the riser.

Fresh coal is fed to the high-pressure reaction system as a slurry using product oil in a 50:50 coal/oil mixture. The coal is dried by the hot effluent gases in a fluidized bed adjacent to the quench bed. The residence times in these two fluidized beds are controlled by controlling the relative heights of the two fluidized beds.

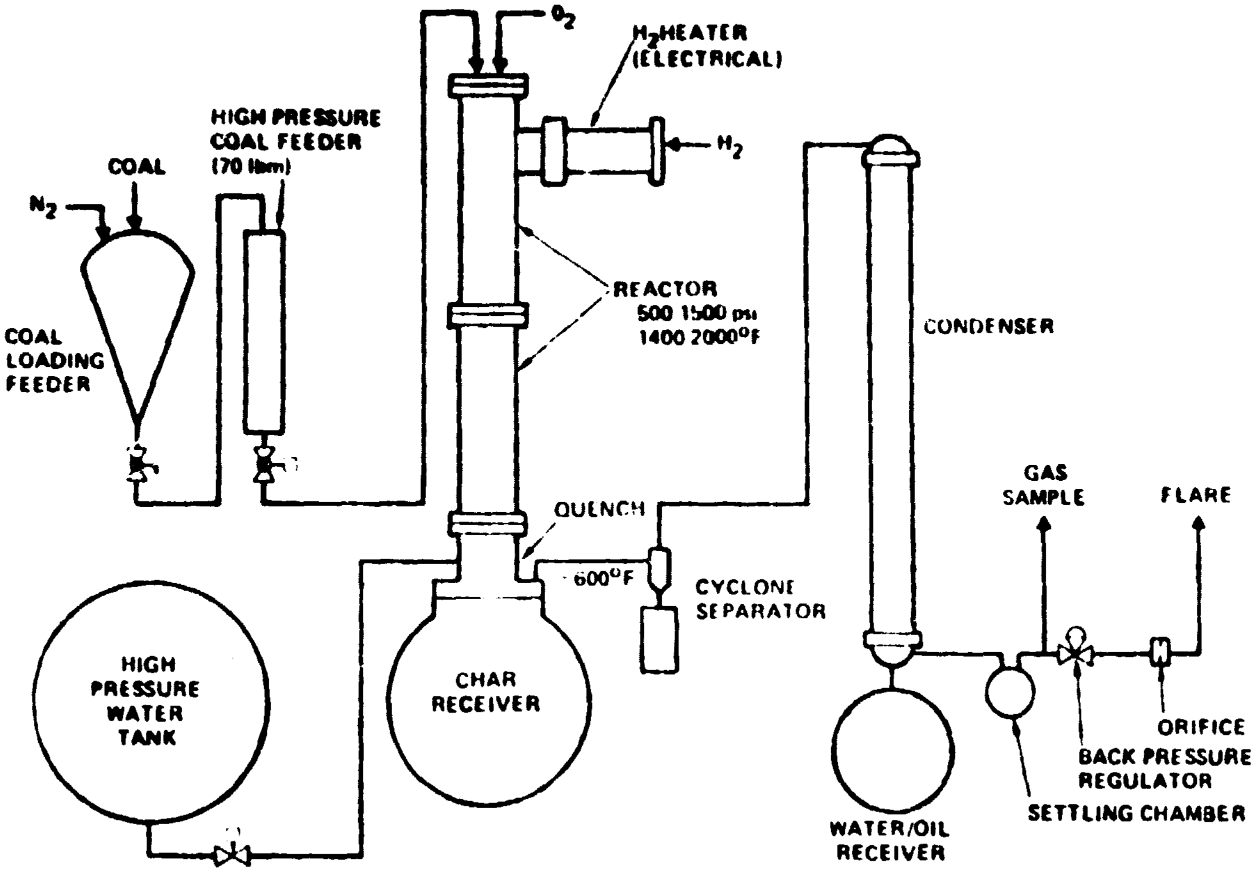
Char from the disengaging vessel is fed to a steam-oxygen gasifier operating at reaction system pressure (up to 2000 psig).

In the bench-scale work SRT hydrogenolysis char has been rerun in the reactor with an additional yield of heavy oils; thus, an optional char recycle mode is provided in the commercial concept schematic in the event that char recycling should be established as an economic operation.

Hydrogen and product vapors pass from the second cyclone of the disengaging vessel to further cooling and separation. Raw gas from the gasifier proceeds to acid-gas removal and a CO-shift reactor to generate makeup hydrogen. The chemical hydrogen required by the process is about 4 to 5 weight percent of the feed coal, so that roughly 40 to 50 weight percent of the feed coal must be devoted to hydrogen production. This requirement coincides well with the 50% conversion level that is attainable by the SRT hydrogenolysis process using reasonable and practical operating conditions.




RISER CRACKING FLOW DIAGRAM




FLASH LIQUEFACTION FLOW DIAGRAM

## SAMPLE YIELDS (APPROXIMATE)

### RISER CRACKING

| | A | B |
|---|---|---|
| Pressure, psig | 1500 | 2000 |
| Temperature, °F | 1400 | 1500 |
| $H_2$/MAF Lignite Ratio | 0.105 | 0.458 |
| Yields, lb/100 MAF Lignite | | |
| Methane | 8.57 | 13.68 |
| Ethane | 4.11 | 7.43 |
| Propane | 1.13 | 0.23 |
| Light HC Gases | 0.41 | 0.03 |
| Carbon Oxides | 16.54 | 12.98 |
| HC Liquids | 8.83 | 12.69 |
| Water | 15.59 | 22.06 |
| MAF Char | 49.50 | 41.78 |
| Carbon Conversion, % | 36.1 | 44.9 |
| Gasoline in HC Liquids, wt % | 55.5 | 51.3 |

### FLASH LIQUEFACTION

Ranges of Variables Tested

| Coal Source and Type | No. of Runs | $P_R$ (psig) | $T_R$ (°F) | $t_{resid.}$ (msec) | Carbon Conversions (%) Overall | Carbon Conversions (%) To Gases |
|---|---|---|---|---|---|---|
| Montana | 17 | 1000 | 1416 | 600 | 27.8 | 22.5 |
| Rosebud | | to | to | to | to | to |
| Subbituminous | | 1500 | 1900 | 4100 | 49.8 | -49.8 |
| Kentucky | 9 | 1000 | 1624 | 480 | 47.3 | 40 |
| hv A Bituminous | | to | to | to | to | to |
| | | 1500 | 1980 | 5500 | 67.2 | -67.2 |
| Minnesota | 12 | 500 | 1534 | 500 | 73.4 | 63.5 |
| Peat | | to | to | to | to | to |
| | | 1500 | 1850 | 3700 | 84.8 | 84.2 |
| | 1 | 500 | 998 | 800 | 34.2 | 8.8 |

## 4.0 DEVELOPMENT REQUIREMENTS ANALYSIS

Coal liquefaction processes are highly capital intensive and end product costs are sensitive to conversion efficiency and operating conditions. These factors are directly dependent on process control via instrumentation and the efficiency, reliability, and maintainability of equipment, components, and materials. Liquefaction processes differ in chemical reaction, operating pressures, and temperatures, residence times, physical contact between reactants, and composition of the product streams. Improvements in conversion both in economy and efficiency will result in many cases from plant scaleup, higher pressures, higher temperatures, faster reaction rates, and better contact between reactants.

The coal liquefacti n system cannot be more reliable or efficient than its equipment and components. Many current operating problems and shutdowns in pilot and subscale plants are directly attributable to the use of commercial equipment which was not designed for the extreme environments within the conversion systems. For commercial application, equipment and components are needed which will endure these environments over extended periods.

## 4.1 PILOT PLANT OPERATIONAL EXPERIENCE

Selected pilot plant operational experience data was analyzed to identify and characterize key process technology areas, and establish overall technology readiness and development trends. The results of these analyses were compared and synthesized with previous technology and operational problem assessments conducted by SRS and other sources (see Section 8.0 References).

Example equipment and component problems which have occurred at the SRC-I (Wilsonville) and SRC-II (Ft. Lewis) pilot plants are described in Figures 4-1 and 4-2. Certain of these problems were considered maintenance and repair rather than equipment failures.

## SAMPLE PILOT PLANT OPERATIONAL PROBLEMS

| PLANT AREA | EQUIPMENT/COMPONENT | MATERIAL | PROBLEMS |
|---|---|---|---|
| SRC I, WILSONVILLE | | | |
| SOLID SEPARATION | CENTRIFUGE | | TOP OIL SEAL FAILED |
| FILTER FEED PREPARATION | VALVE | TUNGSTEN CARBIDE | TIP BROKE AND LODGED IN VALVE SEAT |
| SOLID SEPARATION | CENTRIFUGE | | TOP OIL SEAL FAILED |
| FILTER FEED PREPARATION | VALVE | | TRIM EROSION |
| FILTER FEED PREPARATION | VALVE | TUNGSTEN CARBIDE STAINLESS STEEL | TRIM EROSION |
| SOLID SEPARATION | CENTRIFUGE | | TOP OIL SEAL LEAKING |
| MINERAL RESIDUE SEPARATION | FILTER | CARBON STEEL | SEAL FACE FAILURE |
| PRODUCT SOLIDIFIER | TRAY JACKET | | DEVELOPED A WATER LEAK |
| VACUUM COLUMN | PIPING | | PIPE COLLAPSED |
| SOLID SEPARATION | CENTRIFUGE | | UNDERFLOW CONE PLUGGED |
| SOLID SEPARATION | CENTRIFUGE | | BEARINGS BADLY WORN |
| SOLID SEPARATION | CENTRIFUGE | | BEARINGS & SEAL DAMAGE |
| VACUUM COLUMN | LIQUID COAL LINE | | PLUGGING DUE TO LOW CONVERSION, AND ASH CONTENT |
| PRECOAT MIX TANK | AGITATOR | | BEARING FAILED |
| FILTER CAKE DISCHARGE | VALVE | | NITROGEN LINES PLUGGED |

:GU 4-1

SAMPLE PILOT PLANT OPERATIONAL PROBLEMS

| PLANT AREA | EQUIPMENT/COMPONENT | MATERIAL | PROBLEMS |
|---|---|---|---|
| FILTER FEED PREPARATION | VALVE | | TRIM EROSION |
| SOLID SEPARATION | CENTRIFUGE/CONVEYOR | | SEAL FAILED, BEARING & HUB DAMAGED |
| SOLID SEPARATION | CENTRIFUGE | | BELLOWS OF THE CASING SEAL LEAKING |
| MINERALS RESIDUE SEPARATION | FILTER | | SPLITS IN SCREEN TRAY |
| PRECOAT MIX TANK | AGITATOR | | SHAFT FAILED |
| SOLID SEPARATION | CENTRIFUGE/CONVEYOR | | UPPER SLEEVE BEARING FAILED |
| MINERAL RESIDUE SEPARATION | FILTER/ RECIRCULATION LINE | STAINLESS STEEL | WELD EROSION IN 90° ELBOWS |
| VACUUM COLUMN | LIQUID COAL FLOW CONTROL VALVE | | HOLE ERODED IN VALVE BODY |
| HYDROGEN RECYCLE | COMPRESSOR | | DEVELOPED A 'KNOCK' |
| MINERAL RESIDUE [illegible]RATION | FILTER | | BROKEN CARBON BEARING |
| MINERAL RESIDUE SEPARATION | FILTER/BODY FLANGE | | LEAKS |
| FILTER FEED PREPARATION | VALVE | TUNGSTEN CARBIDE | TRIM FAILURE |
| HIGH PRESSURE SAMPLER | BALL VALVE | | FAILED DUE TO COKE BUILD UP |
| SOLID SEPARATION | CENTRIFUGE | STAINLESS STEEL | NOZZLES ERODED |

FIGURE 4-1 (CONT'D)

## SAMPLE PILOT PLANT OPERATIONAL PROBLEMS

| PLANT AREA | EQUIPMENT/COMPONENT | MATERIAL | PROBLEMS |
|---|---|---|---|
| SRC I, WILSONVILLE | | | |
| PRECOAT MIX TANK | AGITATOR | | BEARINGS FAILED |
| FRESH HYDROGEN COMPRESSOR | VALVE | | VALVE FAILED |
| INSTRUMENT AIR DRYER | THERMOSTAT | | THERMOSTAT WAS DEFECTIVE |
| SLURRY PREHEATER | BURNER | | FAILED DUE TO COKING |
| DOWTHERM HEATER | CONTROLS | | FROZE DUE TO RUST |
| USF VERTICAL-LEAF FILTER | LEAF DRIVE MOTOR | | FAILED DUE TO ASH BUILDUP |
| FILTRATION SYSTEM | FILTER DISCHARGE VALVE | | LEAKING |
| | FILTER DISCHARGE VALVE | | NOT CLOSING PROPERLY |
| | SPACER GASKET | | LEAKING |
| FILTER FEED PUMPS A & B | | | SEAL FAILED IN BOTH |
| FILTER PRECOAT PUMPS | | | SEAL FAILED |
| SRC UNIT PUMPS | SEALS | | FAILED 43 TIMES |
| | PACKING | | FAILED 6 TIMES |
| | BEARINGS | | FAILED 4 TIMES |
| | CHECK VALVES | | FAILED 3 TIMES |

FIGURE 4-1 (CON'T)

SAMPLE PILOT PLANT OPERATIONAL PROBLEMS

| PLANT AREA | EQUIPMENT/COMPONENT | MATERIAL | PROBLEMS |
|---|---|---|---|
| CSD UNIT PUMPS | SEALS | | FAILED 5 TIMES |
| | PACKING | | FAILED 9 TIMES |
| | CHECK VALVES | | FAILED 2 TIMES |
| | PUMPS | | DEVELOPED LEAKS 3 TIMES |
| HIGH PRESSURE LETDOWN VALVE | TRIM | | TRIM EROSION |
| VACUUM COLUMN FEED VALVE | TRIM | | TRIM EROSION |
| FILTER DISCHARGE VALVE | VALVE | | FAILED DUE TO NITROGEN PURGE DISCONNECTION |
| SLURRY PREHEATER | OUTLET PIPING | | LEAK DEVELOPED IN A WELD SEAM |
| DISSOLVER | BOTTOM HEAD | | LEAK DEVELOPED AT SEALING SURFACES |
| FRACTIONATION COLUMN | 50% POINT THERMOWELL | | LEAK DEVELOPED AT WELD SEAM |
| COLUMN | HEAT EXCHANGER | | LEAK DEVELOPED DUE TO CORROSION |
| FRACTIONATION COLUMN | NOZZLE | | CRACKS DEVELOPED DUE TO STRESS-CORROSION |
| UM COLUMN TRAY | LINE | CARBON STEEL | DEVELOPED A LEAK IN ELBOW |

FIGURE 4-1 (CON'T)

## SAMPLE PILOT PLANT OPERATIONAL PROBLEMS

| PLANT AREA | EQUIPMENT/COMPONENT | MATERIAL | REQUIRED MAINTENANCE FOR TYPICAL 3 MONTH OPERATION |
|---|---|---|---|
| SRC II, WASHINGTON | | | |
| SLURRY BLEND CIRCULATION | DURCO PUMPS | TUNGSTEN STEEL AND/OR CERAMIC | FOUR SEALS REPLACED |
| PREHEATER CHARGE PUMPS | PUMP "A" | | REPACKED FOUR TIMES, CLEANED SIX TIMES, VALVE SEATS INSTALLED |
| | PUMP "B" | | REPACKED THREE TIMES, CLEANED FOUR TIMES, PRESSURE SAFETY VALVE AND DRIVE BEARINGS REPLACED |
| MINERAL SEPARATION AND DRYING | RECYCLE WATER PUMP "B" | | HEAD GASKET REPLACED FOUR TIMES |
| FILTER FEED FLASH VESSEL RECIRCULATION | PUMP | TUNGSTEN CARBIDE | SIX NEW SEALS, NEW SHAFT AND IMPELLER INSTALLED |
| FILTER FEED SURGE VESSEL | PUMP | TUNGSTEN CARBIDE | TWO NEW SEALS, IMPELLER AND SHAFT INSTALLED |
| WASTE TREATMENT | REACTIVATOR | | NEW AGITATOR GEAR INSTALLED |
| GAS SYSTEMS | STRETFORD UNIT | | REPAIR OF THE BOTTOM OF THE SLURRY TANK, SLURRY TANK AGITATOR, AN AIR BLOWER, INSTRUMENTATION AND VALVES; REPLACEMENT OF A CORRODED CIRCULATING PUMP |
| NEW VACUUM FLASH DRUM BOTTOMS PUMPS | PUMP "A" | TUNGSTEN CARBIDE | SIX NEW SEALS INSTALLED |
| | PUMP "B" | TUNGSTEN CARBIDE | ONE NEW SEAL INSTALLED |

FIGURE 4-2

SAMPLE PILOT PLANT OPERATIONAL PROBLEMS

| PLANT AREA | EQUIPMENT/COMPONENT | MATERIAL | REQUIRED MAINTENANCE FOR TYPICAL 3 MONTH OPERATION |
|---|---|---|---|
| COAL-SLURRY MIXING | EXPANSION LOOP PIPING | | HOLE ERODED THROUGH A 45$^\circ$ ELBOW |
| | EXPANSION LOOP PIPING | | PIPE LEAKING |
| SLURRY PREHEATING AND DISSOLVING | VALVE | | LEAK BROKE THROUGH BODY |
| | FLASH VAPOR COOLER | | TUBES LEAKING, CAUSED BY ATTEMPTS TO UNPLUG |
| | HIGH PRESSURE SEPARATOR LEVEL CONTROL VALVE | | TRIM FAILURE |
| | HIGH PRESSURE FLASH DRUM LEVEL CONTROL VALVE | | FLANGES LEAKING |
| | INTERMEDIATE PRESSURE FLASH DRUM LEVEL CONTROL VALVE | | TRIM FAILURE |
| | LEVEL CONTROL VALVE FLANGES | | UNABLE TO TIGHTEN LEAK TIGHT |
| MINERAL SEPARATION AND [illegible]NG | DRYER DRUM | | SECTION OF WALL WAS CARBONIZED |
| SOLVENT RECOVERY | VACUUM FLASH DRUM | | PLUGGING PROBLEMS DUE TO LOW AMOUNT OF SRC TO CARRY OUT SOLIDS AND SENSOR PROBLEMS |
| SLURRY BLEND CIRCULATION PUMPS | DURCO PUMPS | TUNGSTEN CARBIDE | FOUR SEAL FAILURE, ONE CASE ERODED THROUGH |
| NAPHTHA CIRCULATION PUMPS | PUMP NO. 1 | | NEW HEAD GASKET, NEW VALVES AND VALVE SEATS WERE INSTALLED |

FIGURE 4-2 (CON'T)

## SAMPLE PILOT PLANT OPERATIONAL PROBLEMS

| PLANT AREA | EQUIPMENT/COMPONENT | MATERIAL | REQUIRED MAINTENANCE FOR TYPICAL 3 MONTH OPERATION |
|---|---|---|---|
| "A" RECYCLE HYDROGEN COMPRESSOR | COMPRESSOR | SPRING STEEL | BROKEN VALVE SPRINGS REPLACED SEVEN TIMES |
| "B" RECYCLE HYDROGEN COMPRESSOR | COMPRESSOR | | NEW VALVES INSTALLED FOUR TIMES |
| FRESH HYDROGEN COMPRESSOR | COMPRESSOR | SPRING STEEL | HIGH RATE OF VALVE SPRING FAILURES, CHANGE OF OIL USED |

FIGURE 4-2 (CON'T)

## 4.2 SYSTEMS AND EQUIPMENT

(a) Rotating Components: This equipment includes pumps, compressors, hydraulic turbines, and gas expanders. It appears that equipment for essentially all clean stream applications likely to be encountered in coal conversion facilities is generally available except high-pressure oxygen compressors.

Fans and blowers for dirty-gas streams need developmental work, as do expanders for high-temperature service. Hydraulic turbines, which might be used for slurry applications in future coal conversion plants, are not available. Centrifugal pumps for slurry application are essentially unavailable for applications requiring heads in excess of 100 psi and/or high temperatures (300°F and above).

A number of processes require large compressors to supply high-purity oxygen at pressures between 600 and 1200 psia and perhaps higher. Although some commercial oxygen compressors have operated satisfactorily at pressures above 1000 psia, others have been destroyed by fire or explosion; there is currently a considerable disparity of opinion concerning the safety of oxygen compressors which operate at these high pressures. Liquid oxygen gas been supplied to some pilot plants requiring oxygen, so that oxygen compressors have not been required.

(b) Heat Recovery and Utilization: The single area providing the greatest potential for extending U.S. industrial heat-recovery equipment capabilities as related to coal conversion processes appears to be a research, development, and testing program to acquire more physical property and heat transfer data and more reliable design correlations.

Uncertainties include stream compositions, thermo-physical properties, rates of fouling, corrosion and erosion, and methods of designing for heat interchange between process streams which may include unusually large amounts of solids and/or highly viscous liquids. These problems are solvable only by specific research and development, testing, and operating experience.

(c) Valves: The valve and valve-actuator industry is essentially capable of manufacturing in quantity equipment of the size and for the pressure and temperature ranges which would be required in the coal conversion industry. Valve manufacturers do not, however, have sufficient product application experience to predict the continuing functional ability of valves for some of the required applications.

It appears that industry does not make, as a standard production item, any valve suitable for coal conversion letdown service. Modified oil-field choke valves and angle valves are the valves now most successfully used in pilot plants. Special valve trims and valve modifications have extended valve life, but not to the extent that will be required in the future coal conversion industry. Valve life is a consistent problem in harsh environments for most processes.

(d) High-Temperature, High-Pressure Gas Purification: It appears that commercially available, reliable, and economically competitive hot-gas cleanup equipment capable of conditioning raw product gas to the levels required for high-temperature turbine operation will not be available for some time.

## 4.3 INSTRUMENTATION AND CONTROLS

Advanced conversion processes for fossil fuels have created an urgent need for plant equipment that is in many instances beyond the present state-of-the-art of the chemical process industry. This is particularly true in the area of instruments for measurement and control. Much of the existing instrumentation is too unreliable, inaccurate, or inadequate for the requirements of advanced processes. There is little incentive for advancement of instrument technology from the usual commercial equipment suppliers due to undefined specifications, the lack of a significant market, and the effects of the dynamic nature of synthetic fuel technology on equipment requirements. Plant designers face considerable risks in basing designs on specifications for components that may not now exist.

Instrumentation technology has not kept pace with advances in conversion techniques. The technology is lacking to identify the measurements and controls that are needed; this is exemplified by the limited amount of diagnostic and performance instrumentation installed at the pilot plants.

Critical instrument needs are located in the following process systems:

- Transport (dry and slurry)
- Feeding and metering
- Reactor or combustor processing
- Solids and gas separators
- Solids and liquid separators
- Let-down and transport systems
- Product and output quality assurance

High priority problem areas include:

- Temperature
- Multi-phase mass flow
- Letdown
- Phase detection
- On-line analysis
- Level detection
- Viscometry

Instrumentation and control requirements and typical operating environments for various applications are shown in Figure 4-3.

Potential instrumentation and control problems in demonstration plants include:

(a) Onstream Composition Analysis: For most processes, this appears to be beyond current technology for the measurement accuracies and reproducibility desired.

(b) Moisture Content of Coal: Microwave and infrared techniques appear to hold significant promise.

(c) Ph Measurement: Measurement accuracy at high temperatures and pressures is a concern.

(d) Slurry Viscosity Measurement at High Temperature: Erosive slurry viscosity measurement may prove to be impractical with current technology. In some cases, a percent solids measurement may be used as an indirect method of determining viscosity. The ability to measure coal and recycle slurry is critical to process control. Measurements must be accurate and repeatable. High pressures (2000 psig) and temperatures (800°F) in combination with coking and/or caking effects of the slurry combine to create difficulties for instrumentation in slurry level measurement service. Capacitance probes and/or nuclear devices are successfully being applied in low pressure and temperature environments. Differential pressure devices are being employed in higher temperature and pressure applications.

(e) Temperature Measurement: Particular problems are anticipated because of erosion, caking, coking, and high temperatures. The determination of temperature profiles in dissolvers (2850 psig) poses problems due to its $H_2$ environment and resulted effects on the thermocouple wire and sheath materials. Problems associated with physically locating the thermocouples

| INSTRUMENTATION AND CONTROL REQUIREMENTS/TYPICAL OPERATING ENVIRONMENTS | | | | | | | |
|---|---|---|---|---|---|---|---|
| | | OPERATING CONDITIONS | | | | | |
| REQUIREMENT | PROCESS/SYSTEM APPLICATION | PRESS (PSIG) | TEMP (°F) | SOLIDS CONTENT | FLOW RATES | STREAM COMPOSITIONS | PURPOSE |
| Slurry Flow Metering | o Hydroliquefaction<br>o Gasification | to 4000 | to 800 | to 60% | to 5000 gpm | Coal-oils, Residue-oils, Ash/slag in water, Coal-water, $H_2S$ | Monitor and control process flows and waste streams containing solids on continuous basis |
| Solids Measurement in Slurry Streams | o Hydroliquefaction<br>o Gasification | to 4000 | to 800 | to 60% | to 5000 gpm | Coal-oils, Residue-oils, Ash, Slag in water, Coal water, $H_2S$ | Monitor and control process flows and solids containing waste streams on continuous basis |
| Solids Measurement in Gas Streams | o Gas Streams<br>o Turbines, vapor streams from liquefaction processes | to 1500 | to 2000 | Low to 30-40#/ft$^3$ | to 20,000 cfm | Solids plus process gases | Monitor process streams, control of solids to expander turbines and gas turbines on a continuous basis. Limited equipment now available. |
| Solids Levels in High Pressure Vessels | o Lock Hoppers<br>o Fluidized beds | to 1500 | to 500 | to 80#/ft$^3$ | - | Coal, Char, Ash Solids | Some equipment now available |
| Temperatures in High Pressure Vessels | o Gasifiers<br>o Reactors | to 1500 | to 3000-3300 | Variable | - | CO, $CO_2$, $H_2S$, $H_2$ Solids | Need rapid temperature response. Environments contain large quantities of fine solid particles |

Figure 4-3



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where they are needed are also of concern, e.g., large thick walled dissolver vessels.

(f) <u>Lock Hopper Valves</u>: These valves do not appear to be a major problem in the size ranges required. They are expensive but readily available and acceptably reliable.

(g) <u>Pressure Relief Devices</u>: These devices in slurry service are a major problem. One of the main concerns is that of choking of inlets, thus preventing the device from operating. The use of rupture discs under the valves and/or purging will most likely alleviate this to some extent, but the passage of slurry fluids through a relief valve during overpressure conditions causes severe damage to valve internals. Not all overpressures will result in passage of slurry fluids. For example, during minor process overpressure conditions, only gaseous fluids will be released and the valve can be expected to reseat.

The slurry depressuring system is one of the most critical problems in the plant. The problem is one of reducing the high pressure of the slurry in the dissolver effluent separator to near atmospheric pressure. The best approach to this problem appears to be the use of a power recovery device of some kind, however, present technology is not available to accomplish this satisfactorily. An approach which is based on the use of pressure letdown valves is normally used. This approach is a three-stage letdown system with the flexibility of operating with only two stages. The system can also operate with either a balanced or a constant pressure drop between each stage. There are three parallel valves per stage which are used consecutively to insure a

reasonable run time since plant turnarounds are the only permissible time for maintenance to be performed. Adequate purging is provided to prevent the slurry from plugging lines that are not in service. Double block valves are provided upstream of the letdown valve to provide tight shut off capability.

U.S. valve manufacturers have generally taken the approach of modifying a standard valve design rather than developing a new valve for the specific operating conditions. The best experience at the Fort Lewis Pilot Plant for this service has been with an angle valve using tungsten carbide trim. The maximum life achieved to date is approximately two months, however, trim breakage has been as troublesome as trim erosion. Advantages may be gained from the scale up from port sizes in the pilot plant of around 1/8" diameter to 1-1/2" to 2" diameter in a demonstration plant. Materials evaluations for letdown valves indicates that stainless steel valve bodies and tungsten carbide facing for trim are the likely candidates for application in demonstration plants. The fact that there is limited published data that can be used to accurately size valves for these conditions is an impediment to improved valve development.

## 4.4 MATERIALS

(a) Coal Feed: Major problems in coal feeding include erosion in pipes, recirculating pumps, and high pressure slurry feed pumps. Normally, stainless steel and carbon steel is specified. Application of more wear resistant materials would improve reliability, but not necessarily reduce the cost.

Materials such as stellite and tungsten carbide are probable candidates for improved equipment life, but may not solve some chipping, peeling or gouging problems.

Lock hoppers have been limited to pressure differentials of approximately 500 psi; therefore, multiple lock hoppers are required for high pressure feed systems. Lock hopper sealing valves have been prone to leak, particularly in high pressure processes.

Reciprocating pumps and centrifugal pumps are used for coal slurry applications. Reciprocating pumps are limited to about 3000-4000 psi outlet pressure and about 1000-1500 gpm. Centrifugal pumps are limited to 100 psi pressure per stage and even with multistages are limited to 600-800 psia. Both type pumps are limited to 40-60 wt % solids handling.

(b) Preheater: Preheaters are used in slurry systems to heat the slurry mix to about 800°F at 1500 to 2400 psig but up to 4500 psig. A representative preheater is a gas-fired helical tube made with schedule 160, Incoloy 800 pipe with approximately 1700 ft. total length requiring 50 turns. In a full scale commercial plant, the pipe diameter would be approximately 6 inches. The importance of designing preheaters for long maintenance-free life is revealed by the fact that the SRC-1 demo plant preheaters cost over $40 million. This is 6 times the cost of the dissolver and twice the cost of the distillation section. Alternate preheater designs are needed for commercial plant applications.

(c) Reactor/Dissolver: An example dissolver design is a vessel with a 2-1/4 CR-1 mo. steel with a 3/32 inch weld overlay lining of 309L S.S. covered with 3.32

weld overlay of 347 S.S. This reactor is similar to the SRC-II pilot plant reactor which employs 24 ft. ID by 30 ft. tall vertical cylinders. For commercial plants the sizes will likely be much larger; possibly as large as 15 to 25 feet diameter, lengths up to 80 to 130 ft., wall thickness of 10-16 inches and weight up to 2,800 tons. The available vessels will be limited by the weight of the vessel, the plate thickness, the physical size and available fabrication practices.

(d) Heat Recovery: Possible limiting factors in heat recovery are:

- Erosion by fluids which contains solids
- Corrosion
- Fouling and plugging
- Heat transfer characteristics
- Uniform flow distribution
- High temperature and high pressure closures
- Mechanical properties at elevated temperatures

Possible solutions to some of these problems are ceramic linings (if the heat-up and shut-down stress problem can be overcome), and high temperature alloys. Experience with shell-and-tube units is limited to shell diameters of 16 ft., tube lengths of 80 ft., tubesheet thicknesses of 25.5 in., 28 tube passes, area per shell of 40,000 $ft^2$, and weights of 180 tons. Suppliers' guarantees exclude problems associated with solids and residues in the fluid.

(e) Pressure Letdown: Pilot plant experience indicates that the probable mean operating life for the internals of letdown valves is about 45 days. The longest reported life is 4000 hours. This requires a multistream approach including the associated stop valves and control systems. K701 cemented carbide has been used for valve trim with fair success

relative to other materials. Several materials have been tested on lab scale including carbide silicon carbide, alumina, titanium dibromide and ceramic materials. The most promising material was identified as chemically vapor deposited (CVD) silicon carbide.

(f) Solids Separation: A rotary drum filter with a covering of diatomaceous earth appears to be a preferred method of solids removal. Several types of filtration systems (including hydroclones & centrifuges) have been tested. Available methods have been costly and difficult and none have been completely satisfactory.

Potential solutions to general corrosion problems in solvent recovery, the condensate stream, and water treatment systems are shown in Figure 4-4. An example equipment and components materials listing with associated temperature and pressure conditions for a commercial scale liquefaction plant is summarized in Figure 4-5.

## POTENTIAL SOLUTIONS TO CORROSION PROBLEMS

| Type and Location | Solution |
|---|---|
| **Solvent Recovery** | |
| Light general corrosion of bottom end of column and 304 S.S. reboiler tubes in Light Ends Column--Tacoma | 316 S.S. |
| Severe general corrosion and possible S.C.C. of carbon steel, 410 S.S., 304 S.S. in Wash Solvent Column--Tacoma (naphthenic acid and chloride S.C.C.?); P=10psig; T=450-700$^{o}$F | 317 S.S., Incoloy 800, or Hastelloy G |
| Severe general corrosion of 316 S.S., 304 S.S. liner, pitting of 304 S.S., localized attack of HAZ, general attack of weldments, with no corrosion products in Fractionation Column--Wilsonville (naphthenic acid accelerated by Cl or $NH_4Cl$?) | Incoloy 825, Hastelloy G, Hastelloy C, or Titanium (?) |
| **Condensate Stream and Water Treatment** | |
| Sour water general corrosion | Neutralization |
| General corrosion (Ammonia bisulfide) | - |
| Sulfide stress cracking | Hardness < 21R"C" |
| Polythionic S.C.C. | 321 or 347 S.S. |
| **Other** | |
| Organic S (T > 500$^{o}$F) | Steel with Cr > 5-7 wt/o |
| $H_2S/H_2$ attack (T >~ 700$^{o}$F) | Steel with CR > 12 wt/o or 18-8S.S |
| Polythionic acid S.C.C. (Shutdown) | 316L, 321, 347, Carpenter 20 |
| Naphthenic acid (~300-750$^{o}$F) | Hastelloy? |
| Chloride S.C.C. (T > 150$^{o}$F) | Incoloy 800 |
| Dusting (T > 550$^{o}$F; $H_2$+CO) | S tends to mitigate |
| Carburizing | |

FIGURE 4-4

# EQUIPMENT/COMPONENTS - MATERIALS

## COAL PREP AND HANDLING

| ITEM | MATERIAL | PRESSURE (PSIG) | TEMP. (°F) |
|---|---|---|---|
| COAL UNLOADING AND CONVEYING SYSTEM | CS | | |
| PULVERIZED FEED HOPPER CONVEYOR SYSTEM | CS | | |
| COAL PULVERIZER SYSTEM | CS | | |
| COAL PULVERIZER BAG HOUSE | CS | | |
| PULV. COAL PNEUMATIC CONVEYOR | CS | | |
| COAL AIR FLOAT CONVEYOR | CS | | |
| COAL SCREW CONVEYOR | CS | | |
| COAL SILO | CONCRETE | ATM | AMB. |
| PULVERIZED FEED HOPPER | CARBON STEEL (CS) | ATM | AMB. |
| PULVERIZED COAL RECEIVER | CS | ATM | 200 |
| PULVERIZED COAL FEED BIN | CS | ATM | 150 |

## GASIFICATION

| ITEM | MATERIAL | PRESSURE (PSIG) | TEMP. (°F) |
|---|---|---|---|
| COAL FEED PRESSURIZER | SS | | |
| COAL FEED EDUCTOR | 316 | - | |
| CHAR FEED EDUCTOR | | - | |

FIGURE 4-5

## EQUIPMENT/COMPONENTS - MATERIALS

**GASIFICATION** (CONT'D)

| ITEM | MATERIAL | PRESSURE (PSIG) | TEMP. (°F) |
|---|---|---|---|
| GASIFIER WATER CIRCULATION PUMP | CS | 84 | |
| VENTURI RECYCLE WATER PUMP | 304 | 150 | |
| CONVEYING RAW GAS COMPRESSOR | 304 | 140 | |
| VENTURI SLURRY RECYCLE PUMP | 316 | 53 | |
| SLAG DRAIN WATER PUMPS | CS NEOPRENE LINED | 55 | |
| QUENCH CHAMBER | CS SHELL W/309 SS CLAD | 600 | 550 |
| GASIFIER | CrMo | 600 | 650 |
| SLAG LOCKHOPPER | 304L CLAD | 600 | 300 |
| GASIFIER STEAM DRUM | CS | 750 | 650 |
| CONVEYING RAW GAS KNOCKOUT DRUM | 304L CLAD | 600 | 400 |
| LIME PRESSURIZER | SS | | |
| GASIFIER CYCLONE | CS REF. LINED | | |
| HYDROCLONE | 304L | | |

FIGURE 4-5 (Continued)

## EQUIPMENT/COMPONENTS - MATERIALS

GASIFICATION (CONT'D)

| ITEM | MATERIAL |
|---|---|
| SLAG DEWATERING SCREEN | SS |
| SLAG REMOVAL SYSTEM | CS |
| SLAG OVERLAND CONVEYOR | CS |
| CONVEYING RAW GAS STEAM HEATER | 304/304L |
| CONVEYING RAW GAS FEED/ EFFLUENT EXCH. | 304/304L |
| CONVEYING RAW GAS COOLER/ CONDENSER | 304 |
| VENTURI SCRUBBER COOLER | 304 |
| VENTURI RAW GAS SCRUBBER | 304L |

SHIFT, ACID GAS REMOVAL & SULFUR RECOVERY

| ITEM | MATERIAL | PRESSURE (PSIG) | TEMP. ($^{o}F$) |
|---|---|---|---|
| SHIFT CONVERTER | 316 &<br>304 CLAD | 600<br>600 | 650<br>1000 |
| 600 PSIG STEAM DRUM | CS | 750 | 600 |

FIGURE 4-5 (Continued)

## EQUIPMENT/COMPONENTS - MATERIALS

**SHIFT, ACID GAS REMOVAL, & SULFUR RECOVERY** (CONT'D)

| ITEM | MATERIAL | PRESSURE (PSIG) | TEMP. ($^{O}F$) |
|---|---|---|---|
| KNOCKOUT DRUM | 304L CLAD | 600 | 530 |
| KNOCKOUT DRUM | 304L CLAD | 600 | 450 |
| KNOCKOUT DRUM | 304L CLAD | 600 | 340 |
| 65 PSIG STEAM DRUM | CS | 95 | 400 |
| METHANOL KNOCKOUT DRUM | CS | 440 | 312 |
| STEAM DRUM RECYCLE PUMP | CS | 25 | |
| CONDENSATE ($330^{O}F$) CENTRIFUGAL PUMP | 304 | 103 | |
| CONDENSATE ($262^{O}F$) CENTRIFUGAL PUMP | 304 | 108 | |
| CONDENSATE ($140^{O}F$) CENTRIFUGAL PUMP | 304 | 113 | |
| 600 PSIG STEAM SUPERHEATER | 309/304L | | |
| SHIFT CONVERTER INLET/OUTLET EXCHANGER | 309/304L | | |
| 600 PSIG STEAM GENERATOR | 316/65 | | |
| BOILER FEED WATER PREHEATER | 304/CS | | |
| 65 PSIG STEAM GENERATOR | 304/CS | | |
| COLD CONDENSATE PREHEATER I | 304 | | |

FIGURE 4-5 (Continued)

## EQUIPMENT/COMPONENTS - MATERIALS

### SHIFT, ACID GAS REMOVAL, & SULFUR RECOVERY (CONT'D)

| ITEM | MATERIAL | PRESSURE (PSIG) | TEMP. ($^{o}$F) |
|---|---|---|---|
| GAS COOLER | 304 | | |
| COLD CONDENSATE PREHEATER II | 304/CS | | |
| RECTISOL UNIT | PROPRIETARY PROCESS FOR ACID GAS UNIT | | |
| CLAUS UNIT | PROPRIETARY PROCESS FOR SULFUR UNIT | | |
| SCOT UNIT | PROPRIETARY PROCESS FOR TAIL GAS UNIT | | |

### METHANOL SYNTHESIS

| ITEM | MATERIAL | PRESSURE (PSIG) | TEMP. ($^{o}$F) |
|---|---|---|---|
| ZINC OXIDE GUARD CHAMBER | ½ MO | 870 | 500 |
| METHANOL CONVERTER | PROPRIETARY | | |
| STEAM DRUM | PROPRIETARY | | |
| KNOCKOUT DRUM | PROPRIETARY | | |
| SYN-GAS COMPRESSOR (INCLUDES CONDENSATE PUMP & STEAM EJECTOR) | CS | 410 | |
| RECYCLE GAS COMPRESSOR | PROPRIETARY | | |

FIGURE 4-5 (Continued)

## EQUIPMENT/COMPONENTS - MATERIALS

METHANOL SYNTHESIS (CONT'D)

| ITEM | MATERIAL | PRESSURE (PSIG) | TEMP. ($^{o}F$) |
|---|---|---|---|
| BFW RECYCLE PUMP | PROPRIETARY | | |
| RECYCLE GAS COMPRESSOR CONDENSATE PUMP | PROPRIETARY | | |
| RECYCLE GAS COMPRESSOR STEAM EJECTOR | PROPRIETARY | | |
| METHANOL RECOVERY PUMP | CS | 643 | |
| TAIL GAS COMPRESSOR | CS | 48 | |
| SYN-GAS COMPRESSOR RECYCLE COOLER | CS | | |
| RECYCLE GAS PREHEATER | PROPRIETARY | | |
| FEED-EFFLUENT EXCHANGER | PROPRIETARY | | |
| SYN-GAS HEATER | PROPRIETARY | | |
| BFW PREHEATER | PROPRIETARY | | |
| METHANOL CONDENSER | PROPRIETARY | | |
| METHANOL FINAL CONDENSER | PROPRIETARY | | |
| RECYCLE GAS COMPRESSOR STEAM CONDENSER | PROPRIETARY | | |
| TAIL GAS COMP. INTERCOOLER | CS | | |
| TAIL GAS COMP. RECYCLE COOLER | CS | | |
| CRYOGENIC UNIT | -- | | |
| START UP HEATER | PROPRIETARY | | |

FIGURE 4-5 (Continued)

# EQUIPMENT/COMPONENTS - MATERIALS

## AIR SEPARATION PLANT

| ITEM | MATERIAL | PRESSURE (PSIG) | TEMP. ($^{o}F$) |
|---|---|---|---|
| OXYGEN COMPRESSOR | CS | 545 | |
| INSTRUMENT NITROGEN COMPRESSOR | CS | 105 | |
| PLANT NITROGEN COMPRESSOR | CS | 105 | |
| $CO_2$ COMPRESSOR | CS | 600 | |

## ENVIRONMENTAL & POLLUTION CONTROL FACILITIES

| ITEM | MATERIAL | PRESSURE (PSIG) | TEMP. ($^{o}F$) |
|---|---|---|---|
| SOUR CONDENSATE STRIPPER COLUMN | CS | 40 | 350 |
| ACETONE STRIPPER COLUMN | 316L | 35 | 300 |
| SLAG WASH WATER TANK | CS | ATM | AMB |
| DOL. LIME BULK STORAGE SILO | CS | +7 -5 | AMB |
| RECLAIMED WATER TANK | CS EPOXY LINED | ATM | 150 |
| ASH THICKENER OVERFLOW TANK | CS EPOXY LINED | ATM | 150 |
| CONDENSATE SURGE DRUM | CS | 75 | 350 |
| REFLUX DRUM | CS | 30 | 250 |

FIGURE 1-5 (CONT'D)

## EQUIPMENT/COMPONENTS - MATERIALS

ENVIRONMENTAL & POLLUTION CONTROL FACILITIES (CONT'D)

| ITEM | MATERIAL | PRESSURE (PSIG) | TEMP. ($^{O}F$) |
|---|---|---|---|
| ACETONE STRIPPER CONDENSATE DRUM | 316 | 35 | 300 |
| DEGASSING DRUM | 316 | 5 | 250 |
| FORMIC ACID DESTRUCTION DRUM | 316 | 180 | 425 |
| GASIFIER WASTE WATER FEED TANK | 316 | 5 | 200 |
| SLAG CLARIFIER OVERFLOW TANK | CS EPOXY LINED | ATM | 150 |
| CARBONATE CLARIFIER OVERFLOW TANK | CS EPOXY LINED | ATM | 150 |
| SLAG QUENCH MAKEUP TANK | CS | ATM | 150 |
| ACID-OIL NEUTRALIZATION TANK | CS | 20 | 150 |
| COAL PILE RUNOFF LIFT PUMP | RUBBER LINED | 40 | |
| COAL SLUDGE PUMP | RUBBER LINED | 60 | |
| SLAG WASH WATER PUMP | CS | 60 | |
| BOILER I.D. FAN | CS | 0.93 | |
| CONTAMINATED WASTE WATER PUMP | RUBBER LINED | 30 | |

FIGURE 4-5 (Continued)

# EQUIPMENT/COMPONENTS - MATERIALS

## ENVIRONMENTAL & POLLUTION CONTROL FACILITIES (CONT'D)

| ITEM | MATERIAL | PRESSURE (PSIG) | TEMP. ($^{O}F$) |
|---|---|---|---|
| ASH CLARIFIER UNDERFLOW PUMP | RUBBER LINED | 25 | |
| RECLAIMED WATER PUMP | MONEL | 85 | |
| ASH SLUDGE PUMP | RUBBER LINED | 35 | |
| THICKENER OVERFLOW PUMP | RUBBER LINED | 25 | |
| DEOILED WASTE WATER PUMP | CI | 50 | |
| STRIPPER REFLUX PUMP | NIHARD | 65 | |
| REBOILER CONDENSATE PUMP | DI | 60 | |
| STRIPPER BOTTOMS PUMP | NIHARD | 30 | |
| SANITARY SLUDGE PUMP | RUBBER LINED | 20 | |
| SANITARY SLUDGE COMPRESSOR | CS | 10 | |
| SEWAGE LIFT PUMP | RUBBER LINED | 90 | |
| DIGESTED SLUDGE PUMP | RUBBER LINED | 20 | |
| ACETONE STRIPPER BOTTOMS PUMP | 316 | 130 | |
| ACETONE CONDENSATE PUMP | 316 | 25 | |

[illegible]GU 4-5 [illegible]on[illegible]ued[illegible]

## EQUIPMENT/COMPONENTS - MATERIALS

### ENVIRONMENTAL & POLLUTION CONTROL FACILITIES (CONT'D)

| ITEM | MATERIALS | PRESSURE (PSIG) | TEMP. ($^{o}F$) |
|---|---|---|---|
| REBOILER CONDENSATE PUMP | DI | 60 | |
| RAW GAS QUENCH PUMP | CS | 590 | |
| RAW GAS QUENCH PUMP | 316 | 650 | |
| SANITARY SLUDGE PUMP | RUBBER LINED | 20 | |
| SANITARY SLUDGE COMPRESSOR | CS | 10 | |
| SEWAGE LIFT PUMP | RUBBER LINED | 90 | |
| DIGESTED SLUDGE PUMP | RUBBER LINED | 20 | |
| ACETONE STRIPPER BOTTOMS PUMP | 316 | 130 | |
| ACETONE CONDENSATE PUMP | 316 | 25 | |
| REBOILER CONDENSATE PUMP | DI | 60 | |
| RAW GAS QUENCH PUMP | CS | 590 | |
| RAW GAS QUENCH PUMP | 316 | 650 | |
| SLAG SLUDGE PUMP | RUBBER LINED | 17 | |
| CARBONATION FEED PUMP | MONEL | 30 | |
| CARBONATION SLUDGE PUMP | RUBBER LINED | 17 | |

FIGURE 4-5 (Continued)

## EQUIPMENT/COMPONENTS - MATERIALS

ENVIRONMENTAL & POLLUTION CONTROL FACILITIES (CONT'D)

| ITEM | MATERIALS | PRESSURE (PSIG) | TEMP. ($^{o}F$) |
|---|---|---|---|
| PRIMARY EVAPORATOR FEED PUMP | MONEL | 55 | |
| SLAG QUENCH EVAP. SPRAY PUMP | MONEL | 40 | |
| VENTURI EVAP. SPRAY PUMP | MONEL | 40 | |
| SLAG QUENCH BOOSTER PUMP | MONEL | 70 | |
| SLAG QUENCH BLOWDOWN PUMP | MONEL | 20 | |
| SLAG QUENCH MAKEUP PUMP | CS | 525 | |
| VENTURI EVAP. BOOSTER PUMP | 316 | 40 | |
| VENTURI EVAP. BLOWDOWN PUMP | MONEL | 20 | |
| NEUTRALIZED ACID FEED PUMP | RUBBER LINED | 20 | |
| STRIPPER REBOILER | CS | | |
| STRIPPER CONDENSER | CS | | |
| STRIPPER FEED-BOTTOMS EXCHANGER | 316/316L | | |
| ACETONE STRIPPER REBOILER | 316/CS | | |
| ACETONE CONDENSER | 316 | | |
| HEAT RECOVERY EXCHANGER | 316L | | |
| FORMATE DESTRUCTION PREHEATER | 316/CS | | |

FIGURE 4-5 (Continued)

## EQUIPMENT/COMPONENTS - MATERIALS

ENVIRONMENTAL & POLLUTION CONTROL FACILITIES (CONT'D)

| ITEM | MATERIALS | PRESSURE (PSIG) | TEMP. ($^{O}F$) |
|---|---|---|---|
| COAL SOLIDS COAGULANT FEED SYSTEM | FRP/316 | | |
| COAL RUNOFF FLOCCULATING CLARIFIER | CS | | |
| ELECTROSTATIC PRECIPITATOR | CS | | |
| SCRUBBER SLUDGE FILTER | RUBBER LINED | | |
| FLUE GAS DESULFURIZATION SYSTEM | - | | |
| FGD LIME BIN VENT FILTER | CS | | |
| DOL. LIME CONVEYOR | CS | | |
| SLUDGE FIXATION SYSTEM | - | | |
| ASH CLARIFIER | CS EPOXY LINED | | |
| OIL SEPARATOR | CS | | |
| ASH THICKENER | CS EPOXY LINED | | |
| ASH POLYMER FEED | 304/FRP | | |
| ASH CENTRIFUGE | CS RUBBER LINED | | |
| ALUM FEEDER | FRP/316 | | |

FIGURE 4-5 (Continued)

# EQUIPMENT/COMPONENTS - MATERIALS

ENVIRONMENTAL & POLLUTION CONTROL FACILITIES (CONT'D)

| ITEM | MATERIALS | PRESSURE (PSIG) | TEMP. ($^{o}F$) |
|---|---|---|---|
| COMMINUTER | CI | | |
| SANITARY POLYMER FEED | FRP | | |
| PRIMARY SANITARY CLARIFIER | CONCRETE | | |
| INERT WASTE TRANSFER CONVEYOR | CS | | |
| INERT WASTE OVERLAND CONVEYOR | CS | | |
| SULFITE WASTE TRANSFER CONVEYOR SYSTEM | CS | | |
| FIXATION SYSTEM DISCH. CONVEYOR | CS | | |
| SLAG LANDFILL CONVEYOR SYSTEM | CS | | |
| INERT WASTE LANDFILL CONVEYOR SYSTEM | CS | | |
| SLAG CLARIFIER | CS RUBBER LINED | | |
| CARBONATION MIXER | FRP | | |
| CARBONATE CLARIFIER | CS RUBBER LINED | | |
| VAPOR COMPRESSION EVAPORATOR | TITANIUM | | |
| SLAG QUENCH WETTED TUBE EVAPORATOR | 90/10 CU-NI TUBES | | |
| VENTURI RECYCLE WETTED TUBE EVAPORATOR | 90/10 CU-NI TUBES | | |

EQUIPMENT/COMPONENTS - MATERIALS

ENVIRONMENTAL & POLLUTION CONTROL FACILITIES (CONT'D)

| ITEM | MATERIALS | PRESSURE (PSIG) | TEMP. ($^{0}F$) |
|---|---|---|---|
| NEUTRALIZATION TANK AGITATOR | CS | | |

STEAM GENERATION PLANT

| ITEM | MATERIALS | PRESSURE (PSIG) | TEMP. ($^{0}F$) |
|---|---|---|---|
| COAL SILO | STEEL | FULL COAL | AMB |
| PROCESS STEAM GENERATOR BLOWDOWN DRUM | CS | 80 | 375 |
| PROCESS CONDENSATE FLASH DRUM | CS | 80 | 375 |
| L.P. CONDENSATE DRUM | CS | 65 | 362 |
| L.P. BLOWDOWN DRUM | CS | 65 | 362 |
| CONDENSATE COLLECTION TANK | CS | ATM | 175 |
| STEAM GENERATORS BLOW DOWN DRUM | CS | 80 | 375 |
| 1500 PSIG BFW PUMP | CR | 1985 | |
| 600 PSIG BFW PUMP | CR | 745 | |
| 300 PSIG BFW PUMP | CR | 375 | |
| 65 PSIG BFW PUMP | CR | 95 | |
| PROCESS CONDENSATE RETURN PUMP | DI | 67 | |
| L.P. COLD CONDENSATE RETURN PUMP | CS | 150 | |
| L.P. CONDENSATE PUMP | DI | 132 | |

FIGURE 4-5 (Continued)

## EQUIPMENT/COMPONENTS - MATERIALS

**STEAM GENERATION PLANT** (CONT'D)

| ITEM | MATERIALS | PRESSURE (PSIG) | TEMP. ($^{O}F$) |
|---|---|---|---|
| L.P. BLOW DOWN PUMP | DI | 50 | |
| STEAM GENERATOR BLOWDOWN PUMP | DI | 115 | |
| HP BFW PREHEATER | 304/CS | | |
| CHEMICAL INJECTION UNITS | 304/CS | | |
| 1500/600 PSIG DESUPERHEATERS | 304/CS | | |
| 600/300 PSIG DESUPERHEATERS | 304/CS | | |
| 300/65 PSIG DESUPERHEATERS | 304/CS | | |

**METHANOL CONVERSION**

| ITEM | MATERIALS | PRESSURE (PSIG) | TEMP. ($^{O}F$) |
|---|---|---|---|
| METHANOL STRIPPER | CS | 300 | 90 |
| DME REACTOR | MN - ½ MO | 365 ~~300~~ | 820 ~~900~~ |
| CONVERSION REACTOR | MN - ½ MO | 345 ~~300~~ | 810 ~~1000~~ |
| PRODUCT SEPARATOR | 316 CLAD | 260 | 400 |
| VENT CONDENSOR SEPARATOR | 316 CLAD | 260 | 400 |
| REGENERATION K.O. DRUM | CS | 311 | 425 |
| METHANOL FLASH DRUM | CS | 175 | 160 |

FIGURE 4.5 (Continued)

## EQUIPMENT/COMPONENTS - MATERIALS

METHANOL CONVERSION (CONT'D)

| ITEM | MATERIALS | PRESSURE (PSIG) | TEMP. ($^{O}F$) |
|---|---|---|---|
| METHANOL STRIPPER REFLUX DRUM | CS | 90 | 300 |
| RECYCLE GAS COMPRESSOR | CS | 106 | |
| PRODUCT PUMP | CS | 171 | |
| REGENERATION AIR COMPRESSOR | CS | 280 | |
| REGENERATION COMPRESSOR | CS | 60 | |
| EVACUATION EJECTOR | CS | 6"HGA | |
| METHANOL STRIPPER REFLUX FUMP | CS | 55 | |
| METHANOL STRIPPER BOTTOMS PUMP | CS | 30 | |
| HYDROCARBON QUENCH PUMP | CS | 30 | |
| REGENERATION GAS COOLER | CS | | |
| REGENERATION RECYCLE GAS EXCHANGER | C-½MO/CS | | |
| REACTOR EFFLUENT STEAM GENERATOR | C-½MO/CS | | |
| REACTOR EFFLUENT RECYCLE GAS EXCHANGER | - | | |
| REACTOR EFFLUENT FEED EXCHANGER | - | | |
| REACTOR EFFLUENT COOLER | 316 | | |
| NET OFF GAS VENT CONDENSER | 316/CS | | |
| METHANOL STRIPPER CONDENSER | CS | | |

FIGURE 4-5 (Continued)

## EQUIPMENT/COMPONENTS - MATERIALS

METHANOL CONVERSION (CONT'D)

| ITEM | MATERIALS | PRESSURE (PSIG) | TEMP. ($^{O}F$) |
|---|---|---|---|
| METHANOL STRIPPER VENT CONDENSER | CS | | |
| METHANOL STRIPPER REBOILER | CS | | |
| METHANOL STRIPPER PR[illegible]T COOLER | CS | | |

GAS FRACTIONATION

| ITEM | MATERIALS | PRESSURE (PSIG) | TEMP. ($^{O}F$) |
|---|---|---|---|
| DEETHANIZER | CS | 410 | 420 |
| DEPROPANIZER | CS | 245 | 380 |
| DEISOBUTANIZER | CS | 110 | 327 |
| DEBUTANIZER | CS | 76 | 320 |
| DEETHANIZER REFLUX DRUM | CS | 410 | 420 |
| DEPROPANIZER REFLUX DRUM | CS | 245 | 360 |
| DEISOBUTANIZER REFLUX DRUM | CS | 110 | 327 |
| DEBUTANIZER REFLUX DRUM | CS | 76 | 320 |
| DEETHANIZER REFLUX PUMP | CS | 48 | 25 |
| DEPROPANIZER REFLUX PUMP | CS | 108 | 300 |
| DEISOBUTANIZER REFLUX PUMP | CS | 68 | 300 |

FIGURE 4-5 (Continued)

## EQUIPMENT/COMPONENTS - MATERIALS

GAS FRACTIONATION (CONT'D)

| ITEM | MATERIALS | PRESSURE (PSIG) | TEMP. ($^{\circ}F$) |
|---|---|---|---|
| DEISOBUTANIZER BOTTOMS PUMP | CS | 25 | 75 |
| DEBUTANIZER REFLUX PUMP | CS | 68 | 125 |
| DEBUTANIZER BOTTOMS PUMP | CS | 46 | 125 |
| MAKEUP I-$C_4$ ALKYLATION FEED PUMP | CS | 98 | 7.5 |
| $C_4$ ALKYLATION FEED PUMP | CS | 128 | 60 |
| DEETHANIZER CONDENSER/CHILLER | CS | | |
| DEETHANIZER REBOILER | CS | | |
| DEPROPANIZER CONDENSER | CS | | |
| DEPROPANIZER REBOILER | CS | | |
| DEISOBUTANIZER CONDENSER | CS | | |
| DEISOBUTANIZER REBOILER | CS | | |
| DEBUTANIZER CONDENSER | CS | | |
| DEBUTANIZER REBOILER | CS | | |
| DEPROPANIZER FEED/DEISOBUTANIZER BOTTOMS EXCHANGER | CS | | |
| DEISOBUTANIZER FEED/SIDESTREAM EXCHANGER | CS | | |
| DEISOBUTANIZER FEED/DEBUTANIZER BOTTOMS EXCHANGER | CS | | |

FIGURE 4-5 (Continued)

# EQUIPMENT/COMPONENTS - MATERIALS

GAS FRACTIONATION (CONT'D)

| ITEM | MATERIALS | PRESSURE (PSIG) | TEMP. ($^{\circ}F$) |
|---|---|---|---|
| DEBUTANIZER BOTTOMS/DEETHANIZER FEED EXCHANGER | CS | | |
| STABILIZED GASOLINE COOLER | CS | | |
| STABILIZED GASOLINE FINAL COOLER | CS | | |
| I-$C_4$ COOLER | CS | | |
| $C_3$ LPG COOLER | CS | | |

LPG DRYING

| ITEM | MATERIALS | PRESSURE (PSIG) | TEMP. ($^{\circ}F$) |
|---|---|---|---|
| $C_3$ LPG DRYING TOWER | CS | $\frac{300}{310}$ | 160 |
| $C_4$ LPG DRYING TOWER | CS | $\frac{130}{140}$ | 175 |
| $CaCl_2$ BRINE STORAGE TANK | CS | 14 | 280 |
| ANTI-OXIDANT TANK | CS | 14 | 300 |
| ANTI-ICING TANK | CS | 8" $H_2O$ AT TOP | 250 |
| ADDITIVE TANK | CS | 14 | 300 |
| $CaCl_2$ BRINE STORAGE PUMP | CI | 22 | |
| ANTI-OXIDANT PUMP | CS | 50 | |

FIGURE 4-5 (Continued)

# EQUIPMENT/COMPONENTS - MATERIALS

**LPG DRYING** (CONT'D)

| ITEM | MATERIALS | PRESSURE (PSIG) | TEMP. ($^{o}F$) |
|---|---|---|---|
| ANTI-ICING PUMP | CS | 50 | |
| ADDITIVE PUMP | CS | 50 | |
| GASOLINE PRODUCT COOLER | CS | | |

**PRODUCT STORAGE & SHIPPING**

| ITEM | MATERIALS | PRESSURE (PSIG) | TEMP. ($^{o}F$) |
|---|---|---|---|
| STRIPPED METHANOL TANK | CS | ATMOS | 115 |
| INTERMEDIATE $C_4$ LPG SPHERE | CS | 125 | 115 |
| INTERMEDIATE ALKYLATE TANK | CS | ATMOS | 115 |
| INTERMEDIATE STABILIZED GASOLINE TANK | CS | ATMOS | 115 |
| INTERMEDIATE I-$C_4$ SPHERE | CS | 125 | 115 |
| PRODUCT RUNDOWN I-$C_4$ SPHERE | CS | 125 | 115 |
| $C_3$-LPG PRODUCT "BULLETS" | CS | 250 | 115 |
| I$C_4$ PRODUCT SPHERE | CS | 125 | 115 |
| GASOLINE PRODUCT TANK | CS | ATMOS | 115 |
| STRIPPED METHANOL PUMP | CS | 354 | |
| INTERMEDIATE $C_4$-LPG PUMP | CS | 79 | |

FIGURE 4-5 (Continued)

## EQUIPMENT/COMPONENTS - MATERIALS

PRODUCT STORAGE & SHIPPING (CONT'D)

| ITEM | MATERIALS | PRESSURE (PSIG) | TEMP. ($^{O}F$) |
|---|---|---|---|
| INTERMEDIATE ALKYLATE PUMP | CS | 128 | |
| STABILIZED GASOLINE PUMP | CS | 132 | |
| INTERMEDIATE I-$C_4$ PUMP | CS | 40 | |
| PRODUCT RUNDOWN I-$C_4$ PUMP | CS | 53.7 | |
| $C_3$-LPG PRODUCT PUMP | CS | 35.4 | |
| I-$C_4$ PRODUCT PUMP | CS | 14.2 | |
| GASOLINE PUMP | CS | 22.7 | |
| TRANSPORT PUMP | CS | 98 | |
| I-$C_4$ VAPOR RECOVERY SYSTEM | CS | | |

FIGURE 4-5 (Continued)

## 5.0 DOE FOSSIL ENERGY COAL LIQUEFACTION ADVANCED RESEARCH AND TECHNOLOGY DEVELOPMENT

The DOE Fossil Energy Advanced Research and Technology Development (AR&TD) program is structured as presented in Figure 5-1. This program covers a diverse group of activities ranging from applied research to R&D supporting efforts.

Its principal objectives are:

- To provide for a central applied research focus for all program areas of Fossil Energy
- To provide a foundation for innovative technology leading to advanced processes through programs in the DOE Energy Technology Centers (ETCs), National Laboratories (NLs), other government agencies, private industry, and universities
- To facilitate reliable and efficient operation of synthetic fuel plants through materials and components research
- To accelerate direct utilization of coal or coal-derived synfuels through technology development for combustion systems, heat exchangers and control systems, including applications to heat engines and fuel cells
- To assess the viability of Fossil Energy processes under development in terms of national needs, economic, social and environmental constraints and benefits.

AR&TD projects are carried out approximately 50 percent by industry, 25 percent by ETCs, NLs, and other Government agencies, and 25 percent by universities.

C-2

DEPARTMENT OF ENERGY

FOSSIL ENERGY

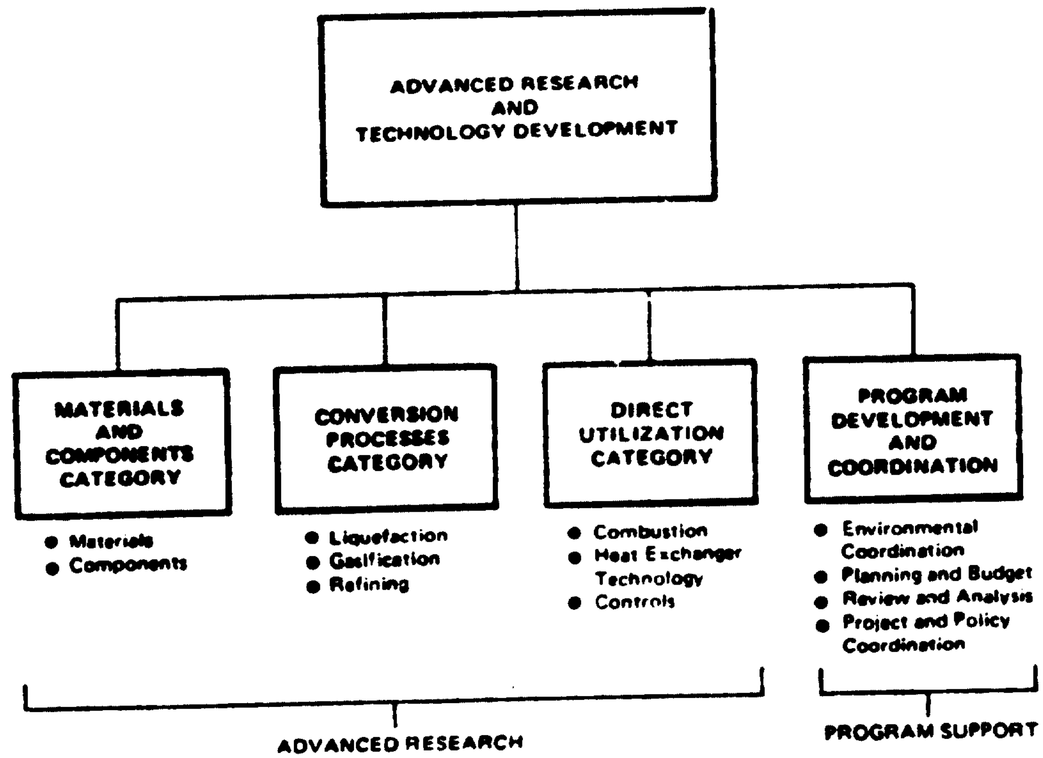



FIGURE 5-1

## 5.1 INDUSTRY AND ENERGY TECHNOLOGY CENTERS

The goals of the DOE sponsored research by industry and energy technology centers are to (1) develop through the bench scale advanced processes that show promise for the direct or indirect liquefaction of coal to low-sulfur, liquid boiler fuels, and distillate syncrudes; and (2) develop processes for direct production of fuels such as gasoline, diesel fuel, and furnace oil by upgrading and refining coal-derived syncrudes.

The major research categories for coal liquefaction are:

- o Extraction
  - Short-residence-time liquefaction
  - Donor solvent interactions
- o Catalytic Hydroliquefaction
  - Mechanism of catalyst deactivation
  - Slurry catalyst process
- o Indirect Liquefaction
  - Exploratory catalyst research
  - Reaction mechanism
- o Supporting Research
  - Examples include:
    - Structure of coal and preasphaltenes
    - Mechanism of coal hydroliquefaction
    - Catalytic reactor modeling design
    - Thermodynaimcs
    - Analytical chemistry of coal and coal liquids
    - Organic chemistry of coal
- o Materials and Components
  - Conduct failure analysis
  - Erosion, corrosion, fatigue, etc. studies
  - Selection of materials

A synopsis listing of the DOE sponsored activities is given in the following table:

## INDUSTRY AND ENERGY TECHNOLOGY CENTERS

| PROJECT TITLE | DESCRIPTION | CONTRACTOR, CITY, & PRINCIPAL INVESTIGATOR (PI) | WORK LOCATION |
|---|---|---|---|
| Investigation of Fuels Containing Coal-Oil-Water Emulsions | Direct Utilization-Evaluate combustion of coal-oil-water slurries | Germantown Labs, Inc. Philadelphia, PA | Philadelphia, PA |
| Coal Fuels Combustion Mechanisms | Direct Utilization-Measure combustion properties of coal | Lawrence Berkeley Lab., Berkeley, CA PI-R.F. Sawyer | Berkeley, CA |
| Materials Research for Clean Utilization of Coal | Materials and Components-Develop equipment and test methods for coal gasification environments | National Bureau of Standards PI-S. Schneider | Gaithersburg, MD |
| Inspection Techniques for Wear-and Process-Resistant Coatings | Materials and Components-Develop nondestructive techniques for inspecting protective coatings | Oak Ridge National Lab., Oak Ridge, TN PI-R.W. McClung & G.W. Scott | Oak Ridge, TN |
| Fracture Toughness of Candidate Steels for Pressure Vessels | Materials and Components-Characterize tensile and fracture toughness of steels | Oak Ridge National Lab., Oak Ridge, TN PI-D.A. Canonico | Oak Ridge, TN |
| Techniques for Welding & Cladding | Materials and Components-Study cladding and field-welding technologies for coal gasifier steels | Oak Ridge National Lab., Oak Ridge, TN PI-D.P. Edmonds & G.M. Goodwin | Oak Ridge, TN |
| Wear-Resistant Alloys for Coal Handling | Materials and Components-Develop wear-resistant alloys for coal transportation and fragmentation equipment | Lawrence Berkeley Lab., Berkeley, CA | Berkeley, CA |
| Low Alloy Steels | Materials and Components-Develop low-alloy steels for thick wall pressure vessels | Lawrence Berkeley Lab., Berkeley, CA | Berkeley, CA |

## INDUSTRY AND ENERGY TECHNOLOGY CENTERS

| PROJECT TITLE | DESCRIPTION | CONTRACTOR, CITY, & PRINCIPAL INVESTIGATOR (PI) | WORK LOCATION |
|---|---|---|---|
| Commercial H-Coal Plant | Construct a commercial H-coal plant having maximum reliability of operation with minimum capital and operating costs | Ashland Synthetic Fuel , Inc. Ashland, KY | Catlettsburg, KY |
| Zinc Halide Hydrocracking Process | Produce clean gaseous and liquid fuels from coal with particular emphasis on gasoline | Conoco Coal Development Co. Library, PA | Library, PA |
| Hydroliquefaction Using Disposable Catalysts | Improve the economics of the original Bergius process while simultaneously producing a low-sulfur fuel | Pittsburgh Energy Technology Center Bruceton, PA | Bruceton, PA |
| Exxon Donor Solvent Process | Achieve commercial readiness in 1982 by obtaining all of the data needed for a commercial plant design | Exxon Research and Engineering Co. Florham Park, NJ | Florham Park, NJ |
| Advanced Coal Liquefaction Commercial Plant | Design a commercial facility to produce liquid synthetic fuels by an advanced coal liquefaction scheme | Fluor Engineers and Constructors, Inc. Los Angeles, CA | Los Angeles, CA Irvine, CA |
| CO-Steam Process | Develop an economic second-generation process for liquefaction of low-level coals | Grand Forks Energy Technology Center | Grand Forks, ND |
| Recovery of Oils and Gases by Pyrolysis | Develop and determine the effects of pyrolytic processes for recovering oil from residues | Pittsburgh Energy Technology Center Bruceton, PA | Bruceton, PA |
| Hydrocarbonization Research | Provide yield data for optimizing various processes | Oak Ridge National Lab., Oak Ridge, TN PI-H.D. Cochran, Jr. | Oak Ridge, TN |

## INDUSTRY AND ENERGY TECHNOLOGY CENTERS

| PROJECT TITLE | DESCRIPTION | CONTRACTOR, CITY, & PRINCIPAL INVESTIGATOR (PI) | WORK LOCATION |
|---|---|---|---|
| Refractory Linings for Coal Gasification Equipment | Materials and Components-Determine effect of coal gasifier environments on commercially available refractory lining materials | U.S. Dept. of Interior, Bureau of Mines/Tuscaloosa Metallurgy Research Center, Tuscaloosa, AL | Tuscaloosa, AL |
| Coal Liquefaction Systems Failure Prevention and Analysis | Materials and Components-Examine failed and used components from conversion plants in U.S. to service conditions anticipated in commercial plants | Oak Ridge National Lab., Oak Ridge, TN PI-R.T. King | Oak Ridge, TN |
| Evaluation of Heat Exchanger Materials | Materials and Components-Obtain engineering data pertaining to materials used in fluidized-bed combustion | Battelle, Columbus Laboratories Columbus, OH | Columbus, OH |
| Valve Testing and Development | Materials and Components-Produce long-life valves for handling solids feed and removal in coal conversion reactors | Morgantown Energy Technology Center Morgantown, WV | Morgantown, WV |
| Coal Slurry Feed System | Materials and Components-Develop and test a steam-dried slurry feed system for injecting dry crushed coal into a high pressure process | Morgantown Energy Technology Center Morgantown, WV | Morgantown, WV |
| Industrial Coal Conversion Equipment | Materials and Components-Identify the ability of industry to supply needed equipment for coal demonstration plants | Oak Ridge National Lab., Oak Ridge, TN | Oak Ridge, TN |
| Coal Equipment Test Program | Materials and Components-Examine specific equipment requirements for coal conversion demonstration plants | Oak Ridge National Lab., Oak Ridge, TN | Oak Ridge, TN |

## INDUSTRY AND ENERGY TECHNOLOGY CENTERS

| PROJECT TITLE | DESCRIPTION | CONTRACTOR, CITY, & PRINCIPAL INVESTIGATOR (PI) | WORK LOCATION |
|---|---|---|---|
| Lock Hopper Valve Development | Materials and Components-Design, manufacture, test, and evaluate valves for gasification plants | Consolidated Controls El Segundo, CA | El Segundo, CA |
| Alloy Evaluation-Liquefaction | Materials and Components-Evaluate the effect of a liquefaction dissolver environment on the mechanical property integrity of steel | Ames Lab., Mountain View, CA PI-T.E. Scott | Mountain View, CA |
| Evaluation of Fracture Toughness of Pressure Vessel Steels | Materials and Components-Determine the effect of the operating environment of coal conversion systems on high and low-temperature properties of pressure vessel steels | Oak Ridge National Lab., Oak Ridge, TN | Oak Ridge, TN |
| Characterization of Coal-Derived Liquids | Materials and Components-Provide physical/chemical data which would systematically relate coal grade to its liquid hydrocarbon structuring | Bartlesville Energy Technology Center Bartlesville, OK | Bartlesville, OK |
| Management and Coordination of Coal Science Tasks | Materials and Components-Assist the Division of Coal Conversion/Liquefaction and the Office of University Activities in coordinating coal science projects | Pittsburgh Energy Technology Center PI-A.G. Sharkey, Jr. & H.L. Retcofsky | Bruceton, PA |
| Plastic Heat Exchangers for Waste Heat Recovery | Materials and Components-Develop low-cost plastic heat exchangers to be used to conserve low-temperature waste heat | Argonne National Lab. PI-R.E. Holtz & R.N. Koopmans | Argonne, IL |
| Heat Exchanger Tube Vibrations | Materials and Components-Test segmentally baffled shell-and-tube heat exchangers, and quantity tube vibration data | Argonne National Lab. Argonne, IL | Argonne, IL |

## INDUSTRY AND ENERGY TECHNOLOGY CENTERS

| PROJECT TITLE | DESCRIPTION | CONTRACTOR, CITY, & PRINCIPAL INVESTIGATOR (PI) | WORK LOCATION |
|---|---|---|---|
| Optimizing Chromium Molybdenum Steels to Resist Hydrogen and Temper Embrittlements | Materials and Components-Evaluate and optimize the resistence to hydrogen, and temper embrittlement susceptibility of chromium-molybdenum steels fur use as structural materials in coal conversion pressure vessels | Westinghouse Electric Corp. | Pittsburgh, PA |
| Development of Wear-Resistant Valve Materials | Materials and Components-Develop and identify improved wear-resistant materials to be used for valve trim | Bureau of Mines, Albany Metallurgy, Research Center | Albany, NY |

## 5.2 UNIVERSITY ACTIVITIES

University research on coal conversion and utilization sponsored by DOE includes research in the following topics:

- Combustion of coal and synthetic fuels
- Coal characterization and specificity as related to liquefaction and gasification processes
- The structure and reactions of coal and analysis of its conversion products
- Multiphase flow phenomena related to coal conversion processes
- Fundamental problems of reactor engineering
- Environmental aspects directly related to coal conversion processes and coal utilization.

Research on other coal-related topics is also being supported if the proposals are submitted and offer exceptionally pertinent, promising or novel ideas for advancing our knowledge of coal conversion and utilization.

The following is a synopsis listing of the university activities in research on coal conversion and coal utilization:

## UNIVERSITY ACTIVITIES

| PROJECT TITLE | DESCRIPTION | CONTRACTOR, CITY, AND PRINCIPAL INVESTIGATOR (PI) | WORK LOCATION |
|---|---|---|---|
| Wear Resistant Alloys for Coal Handling Equipment | Develop wear resistant alloys for coal transportation and fragmentation | Univ. of Calif. at Berkeley PI-F.R. Parker & V.F. Zackay | Berkeley, CA |
| Corrosion of Materials in Contact with Coal Chars | Determine reaction of six super-alloys exposed to coal chars at elevated temperatures for long periods | Univ. of Calif. at Los Angeles PI-D.L. Douglass | Los Angeles, CA |
| Coal Anion Chemistry and Structure | Develop new methods for coal alkylation | Univ. of Chicago PI-L.M. Stock | Chicago, IL |
| Analysis of Designs for Coal Conversion Pressure Vessels | Develop larger vessels for coal gasification plants | Univ. of Kentucky PI-D.C. Leigh & T.R. Tauchert | Lexington, KY |
| Properties of Coal Slags | Assemble data on thermodynamic behavior of coal ash | Mass. Inst. of Tech. PI-J.F. Elliott & G.J. Yurek | Cambridge, MA |
| Gas Clean-Up of Particulates | Investigate application of electrofluidized bed to the collection of particulate products of combustion | Mass. Inst. of Tech. Energy Laboratory PI-J.F. Louis & J.R. Melcher | Cambridge, MA |
| Catalytic Hydro-liquefaction/Hydro-gasification of Lignite | Investigate basic chemical kinetics and mechanisms of the catalytic hydrogenation of lignite | Worcester Polytechnic Institute PI-W.L. Kranich & A.H. Weiss | Worcester, MA |
| Pyrolytic Conversion of Coal to Clean Fuel | Develop mathematical model for coal pyrolysis | Princeton University PI-M. Summerfield | Princeton, NJ |

## UNIVERSITY ACTIVITIES

| PROJECT TITLE | DESCRIPTION | CONTRACTOR, CITY, AND PRINCIPAL INVESTIGATOR (PI) | WORK LOCATION |
|---|---|---|---|
| Desulfurization with Transition Metal Catalysts | Evaluate mechanism and efficiency of transition metal desulfurizing agents | State Univ. of NY at Binghamton PI-J.J. Eisch | Binghamton, NY |
| Interaction of H-Atoms with Coal Dust | Identify and quantify the gasoline-type hydrocarbons produced by the interaction of H-atoms with fine coal dust above 175°C | Oklahoma State Univ. Stillwater, OK PI-G.J. Mains | Stillwater, OK |
| Recirculating Bed Reactors for Coal Processing | Facilitate the application of recirculating bed reactors coal processing | Carnegie-Mellon Univ. PI-T.W. Bierl & M.J. Massey | Pittsburgh, PA |
| Advanced Methanol Syntheses Catalysts | Investigate advanced catalytic systems for synthsizing methanol and methyl fuel from coal-generated syngas | Lehigh Univ. PI-K. Kiler | Bethlehem, PA |
| Hydrogen Distribution in Coal Hydrogenation Systems | Investigate hydrogen behavior in coal hydrogenation systems to provide design data for liquefaction | Univ. of Pittsburgh PI-S.H. Chiang | Pittsburgh, PA |
| Ash Removal from Derived Liquids | Investigate extracting hydrophobic coated mineral matter from a coal-derived liquid to an aqueous phase | WV Univ. PI-J.D. Henry, Jr. | Morgantown, WV |
| Metal Catalyzed Reactions of Polyaromatic Compounds | Study conversion methods of polyaromatic substances and coal to similar useful molecular products | Univ. of Wisc. at Madison PI-P.M. Treichel | Madison, WI |
| Application of Liquefaction Processes to Low-Rank Coals | Research the catalytic effects of minerals found in coal on liquefaction reactions | Univ. of No. Dak. Grand Forks, ND | Grand Forks, ND |

## UNIVERSITY ACTIVITIES

| PROJECT TITLE | DESCRIPTION | CONTRACTOR, CITY, AND PRINCIPAL INVESTIGATOR (PI) | WORK LOCATION |
|---|---|---|---|
| Sampling and Analysis of Small Particles from Hot Process Streams | Compare various techniques for measuring particle-size distributions in hot process (coal) streams | Univ. of Ariz. Tucson, AZ | Tucson, AZ |
| Electroslag Welding Procedures | Examine the mechanical integrity of steel electroslag weldments and methods for improving the process | Colorado School of Mines | Golden, CO |
| Analysis of Hydrogen Attack on Pressure Vessel Steels | Establish a data base providing current information on analysis of hydrogen attack on pressure vessel steels | Univ. of Calif. at Santa Barbara PI-G.E. Odette | Santa Barbara, CA |
| Thermal Stability of Iron Alloys | Evaluate the metallurgical stability of iron alloy steels at high temperatures | Univ. of Washington | Seattle, WA |
| Enhanced Combustion of Fossil Fuel Particles and Droplets in Oscillating Flow | Analyze the effects of oscillating air flow on rates of combustion of fossil fuel particles and droplets | Syracuse University PI-F.A. Lyman | Syracuse, NY |
| Chemical Modification and Separation of Preasphaltenes of SRC | Improve the quality of coal-derived fuels by developing methods to control preasphaltenes | Univ. of No. Dak. PI-N.F. Woolsey | Grand Forks, ND |
| Removal of Organic Sulfur from Coal | Develop an efficient solvent extraction process for pre-combustion removal of organic sulfur from coal | Univ. of Toledo PI-D.F. Burton | Toledo, OH |

## UNIVERSITY ACTIVITIES

| PROJECT TITLE | DESCRIPTION | CONTRACTOR, CITY, AND PRINCIPAL INVESTIGATOR (PI) | WORK LOCATION |
|---|---|---|---|
| Monolithic Refractory Creep Behavior | Evaluate the creep behavior (change of shape) of monolithic refractory concretes in relation to their composition | Iowa State Univ. Ames, IA PI-T.D. McGee & J.R. Smyth | Ames, IA |
| Semifluidized-Bed Filters | Evaluate the applicability of semifluidized-bed filters to the filtration of coal wash water and liquefied coal | Kansas State Univ. PI-L.T. Fan | Manhattan, KS |
| Fatigue Crack Growth Factors | Examine the propagation of fatigue cracks in thick-section pressure-vessel steel plates | Mass. Inst. of Tech. Cambridge, MA PI-R.C. Ritchie | Cambridge, MA |
| Stabilized Mixture Study | Determine an organized process for the selection of additives for stabilizing coal-oil mixtures | Tufts University PI-C. Botsaris & Y. Glazeman | Medford, MA |
| Slurry Coal Ash Analyzer | Develop a sensor system for the analysis of ash in coal slurries | Michigan Tech. Univ. PI-S.K. Kewatra | Houghton, MI |
| Gaseous Detonative Fracture | Determine the degree of fracturing achieved by gaseous detonations in porous coal beds | Univ. of Mich. PI-C.W. Kauffman | Ann Arbor, MI |
| Coal Combustion in Opposed Gas-Particle Jet with Regenerative Pyrolysis | Study the effect of regenerative pyrolysis (heat-induced chemical change) on coal combustion | Georgia Inst. of Tech. PI-P. Durbetaki | Atlanta, GA |
| Hydrogen Attack in Steels at Elevated Temperatures | Investigate the structural and mechanical properties of various steels under high temperature and high pressure hydrogen stress | Cornell Univ. PI-Cha-Yu Li | Ithaca, NY |

## 6.0 ECONOMIC ASSESSMENT

### 6.1 EVALUATION OF ECONOMIC ANALYSES

Cost analyses of coal liquefaction processes typically begins while a process is still bench scale and continues to be revised and refined throughout development. The stages of cost estimates may be identified as Feasibility, Preliminary and Definitive.

Feasibility: Feasibility cost estimates are considered to have an accuracy of -30% to +50%. This requires a knowledge of major equipment items, basic flow diagram, regional site location, and general product and supply information. The feasibility estimate is made for management decisions on feasibility for further study.

Preliminary: Preliminary estimates are made for research and development planning and setting technology development priorities. The accuracy range is -15% to +30%. Equipment types and sizes, material balances, materials of construction, building requirements, general site conditions and preliminary layouts, flow charts, plot plans, etc., are required to be known for this type of cost estimate.

Definitive: A definitive cost estimate has an accuracy of -5% to +15%. Required information for this estimate includes quotes on equipment and labor cost, preliminary to complete design drawings, specific product and feed information and specific site conditions. This estimate is used for construction contract negotiations and/or appropriations of funds.

Most cost estimates would normally be based on previous experience of similar type and size projects. Since there are no commercial plants in the U.S. of similar size and type to the proposed coal liquefaction plants, the cost analyses that have been done are based on conceptual designs which include only a limited amount of commercial experience. The Sasol II

(South African Plant Designed by Fluor) cost estimate appears to be the only estimate that is based on commercial plant experience. Since Fluor wants to sell this technology in the U.S., only limited information is openly available on the detailed costs for a plant in the U.S.

Developments during recent years in the areas of oil prices, inflation, and equipment and process definition have diminished the validity of published cost estimates which are based on available conceptual designs. In many cases, these cost estimates have not been properly updated to reflect the drastic change in costs from the time the conceptual design was done. As an example; in 1975, a 20,000 TPD SRC commercial plant was estimated to cost $700 million. The most recent estimate of a demonstration scale plant almost one third the size of a commercial plant was $1.5 billion. This increase in estimated cost is considerably more than the normal discounted price.

Another major problem with cost estimates of commercial scale plants is that very few, if any, are made on an equal basis, therefore, comparison of cost estimates for various processes cannot be made without a detailed analysis of the parameters used in making the estimates. These parameters include the accuracy, the method used, and the background of the estimate (how it was developed, the level of detail used, the sources of cost date, etc.)

## 6.2 PRODUCT COST COMPARISON

Product Cost: The cost of the final product of a coal liquefaction process includes the capital cost of financing and construction, the operating and maintenance cost and the value of the end product. The cost may be evaluated on an energy content basis which does not account for the market value of the various products of a plant. These various products may have value in the market place which are not

related to heating value alone. The reference price accounts for the product market value and the price for all products of a specific plant. A comparison of the product cost estimates is shown in Figure 6-1.

Product Value: The product value may be evaluated by factors which are ratios of market price for the particular product relative to premium gasoline. Ratios between product value factors do not remain constant with time; the value factors may be noticeably different for different years as shown in Figure 6-2.

## 6.3 COMMERCIAL PLANT COST

The major cost elements in commercial plants are capital cost and operating cost.

Capital cost may be stated to include all construction costs including buildings, utilities, contingencies, etc., for a complete plant or may be stated as plant capital cost which only includes the bare plant costs without the buildings, paving, utility requirements, etc., required for an integrated plant.

The plant capital cost shown in Figure 6-3 are bare plant costs. The capital costs shown in Figure 6-4 include the total capital investment required for an integrated plant for each of the major processes.

Plant operating cost includes cost for labor, consumable supplies, maintenance, fees and taxes. Figure 6-4 shows the operating and maintenance cost for each of the processes listed.

## 6.4 LIQUEFACTION DEMONSTRATION PLANTS

Two of the major DOE sponsored liquefaction plants are the SRC I and SRC II projects. These projects are structured in three phases: Phase I is process and detailed engineering design; Phase II is procurement and construction; and Phase III is operation and data acquisition. These phases overlap but costs for each phase will be accounted separately. Figures 6-5 and 6-6 show plant capacities, product slates, total plant cost, and cost for each project phase.

## PRODUCT COST COMPARISON

(Mid 79 $'s)

| Process | Product | Cost | Energy Cost $\$/10^6$ Btu | Energy Cost $\$/10^6$ Btu |
|---|---|---|---|---|
| SRC-I | SRC Solid | 115.68 $/Ton | 3.67 | 7.23 |
| | Fuel Oil | 25.51 $/Bbl | | |
| SRC-II | LPG | 20.98 $/Bbl | 3.95 | 6.10 |
| | Naphtha | 27.28 $/Bbl | | |
| | Fuel Oil | 21.52 $/Bbl | | |
| | Gas | 6.10 $/Bbl | | |
| EDS | Propane | 20.36 $/Bbl | 4.32 | 5.89 |
| | Butane | 22.06 $/Bbl | | |
| | Naphtha | 25.11 $/Bbl | | |
| | Fuel Oil | 20.78 $/Bbl | | |
| | C2 - Gas | 5.89 $\$/10^6$ Btu | | |
| H-Coal Fuel Oil | Naphtha | 23.37 $/Bbl | 3.56 | 5.48 |
| | Fuel Oil | 19.33 $/Bbl | | |
| | Gas | 5.48 $\$/10^6$ Btu | | |
| H-Coal Syncrude | Naphtha | 22.26 $/Bbl | 3.89 | 5.22 |
| | Fuel Oil | 18.42 $/Bbl | | |
| | Gas | 5.22 $\$/10^6$ Btu | | |
| Fischer-Tropsch | Gasoline | 26.96 $/Bbl | 5.41 | 5.99 |
| | LPG | 20.61 $/Bbl | | |
| | No. 2 Oil | 25.54 $/Bbl | | |
| | Fuel Oil | 21.13 $/Bbl | | |
| | Med Btu Gas | 5.99 $\$/10^6$ Btu | | |
| | C2 Gas | 5.99 $\$/10^6$ Btu | | |
| M-Gasoline | Gasoline | 26.70 $/Bbl | 5.26 | 5.34 |
| | LPG | 18.37 $/Bbl | | |

Source: "Coal Conversion Comparisons," ESCOE, July 1979.

Figure 6-1

PRODUCT VALUE COMPARISON

| Product | 1978 $/bbl | Value Factor | |
|---|---|---|---|
| No. 6 Fuel Oil | 12.30=B | 0.70(=B/A) | 0.44 |
| SRC-I Solid | - | 0.63 | 0.40 |
| No. 2 Fuel Oil | 14.90=C | 0.85(=C/A) | 0.71 |
| Naphtha | | | |
| H-Coal | | 0.89 | 0.79 |
| EDS | | 0.88 | 0.78 |
| SRC | | 0.85 | 0.71 |
| LPG | 12.12 | 0.69 | 0.43 |
| Regular Gasoline | 16.30 | 0.93 | 0.87 |
| F-T Gasoline | - | 0.90 | 0.84 |
| Premium Gasoline | 17.50=A | 1.0 | 1.0 |

Notes:
1) H-Syncrude equivalent to No. 2 fuel oil
2) SRC & EDS fuel oils are No. 6 fuel
3) 1970 premium gasoline price was 6.25 $/bbl
4) Market prices from the Oil & Gas Journal - Midwest
5) Identifiers used

Source: "Comparison of Coal Liquefaction Processes," ESCOE, April 1978

Figure 6-2

## COMPARISON OF COMMERCIAL PLANT CAPITAL COSTS

### MAJOR ON-SITE PLANT COST IN MILLIONS OF 1978 $ *

(25000 TPD)

| Category | F-T | M | H-Syn | H-FO | EDS | SRC-I | SRC-II |
|---|---|---|---|---|---|---|---|
| Coal Preparation | 63 | 63 | 84 | 84 | 63 | 63 | 63 |
| $H_2$ or Gasification | 228 | 228 | 158 | 138 | 190 | 152 | 253 |
| $O_2$ Plant | 117 | 175 | 87 | 67 | - | 84 | 129 |
| (t/d) | (11,070) | (21,000) | (7,200) | (5,400) | - | (6,800) | (13,000) |
| Gas Shift | - | 40 | 35 | 30 | - | - | - |
| Acid Gas & Sulfur plants | 57 | 57 | 57 | 57 | 60 | 60 | 60 |
| Reactor Section | 55 | 106 | 210 | 140 | 180 | 160 | 195 |
| Conversion | 100 | 75 | - | - | - | - | - |
| Gas Plant ** | 25 | 10 | 25 | 30 | - | 177 | 30 |
| Flexicoker | - | - | - | - | 160 | - | - |
| Pollution Systems | 40 | 40 | 40 | 40 | 44 | 44 | 44 |
| Solvent Hydro or catalyst prep | 3 | - | - | - | 82 | - | - |
| | 688 | 794 | 696 | 586 | 779 | 740 | 774 |

NOTE: F-T = Fischer-Tropsch
M = M-Gasoline
H-Syn = H-Coal-Syncrude mode
H-FO = H-Coal-Fuel Oil mode
EDS = Exxon Donor Solvent
SRC = Solvent Refined Coal

* Conversion to current $'s requires analysis of updated conceptual designs, some of which do not exist. Cost figures do not include contingencies, buildings, pavings, and utilities and other auxilliaries needed for an autonomous plant.

** M includes HF alkylation; EDS solvent system in Flexicoker; SRC includes filtration.

Source: "Coal Conversion Comparisons," ESCOE, July 1979

Figure 6-3

## CAPITAL AND OPERATION COST DATA

(Million $ Mid 1979)

| Process | Capital* | OPERATING & MAINTENANCE COST | | | | |
|---|---|---|---|---|---|---|
| | | Fuel | Catalyst & Chem. | Labor | Maint. | Local Tax & Ins. |
| SRC-I | 1092 | 246. | 3.0 | 13.8 | 33. | 55. |
| SRC-II | 1262 | 246. | 6.0 | 12.2 | 38.2 | 63. |
| EDS | 1270 | 246. | 6.0 | 12.2 | 38.5 | 64. |
| H Coal: | | | | | | |
| Fuel Oil | 955 | 246. | 6.0 | 12.2 | 29. | 48. |
| Syncrude | 1134 | 246. | 7.0 | 12.2 | 34.3 | 57. |
| FT | 1121 | 246. | 7.0 | 12.2 | 34. | 56. |
| M-Gasoline | 1212 | 246. | 8.5 | 12.2 | 35.5 | 65. |

* Capital includes the total cost to construct the plant plus the added investment for buildings, paving, all utilities and other auxilliaries needed for an autonomous plant. A project contingency of 10% is also included.

Source: "Coal Conversion Comparison," ESCOE, July 1979

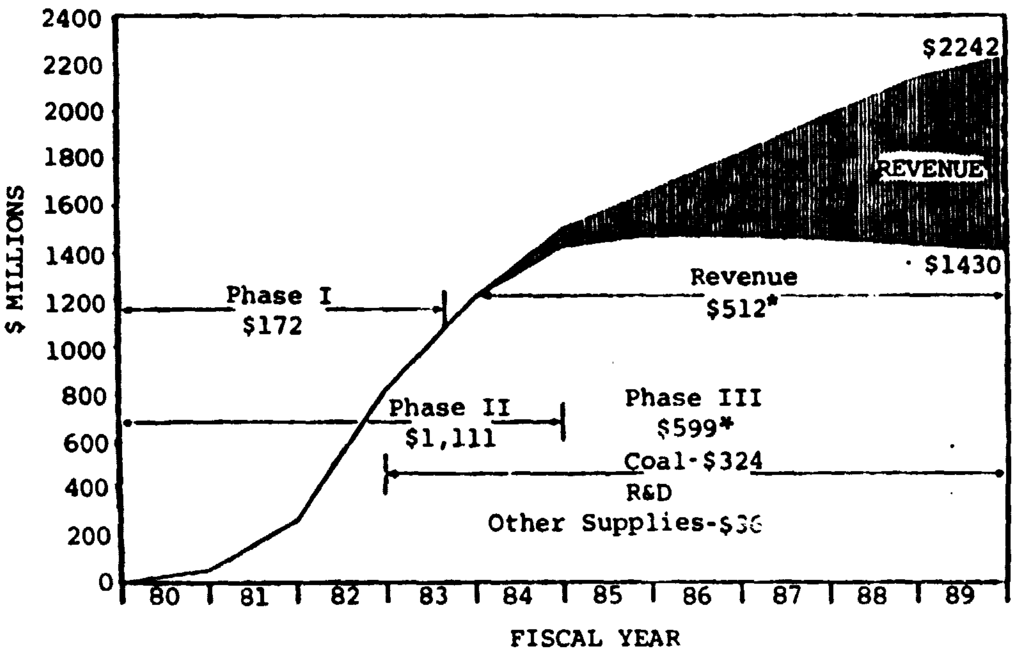
Figure 6-4

## SRC I DEMONSTRATION PLANT

- CAPACITY: 6000 TONS PER STREAM DAY
- PRODUCTS: SOLID PRODUCT ---- 1400 TPSD
  FUEL OILS -------- 1425 TPSD
  COKE ------------- 750 TPSD
  BY-PRODUCTS ------ 250 TPSD
- COST: $1.4 BILLION

SRC I
COST ESTIMATE

PHASE I, II, III




*Phase III Coal & Revenue are not escalated

Source: Oak Ridge National Lab.

Figure 6-5

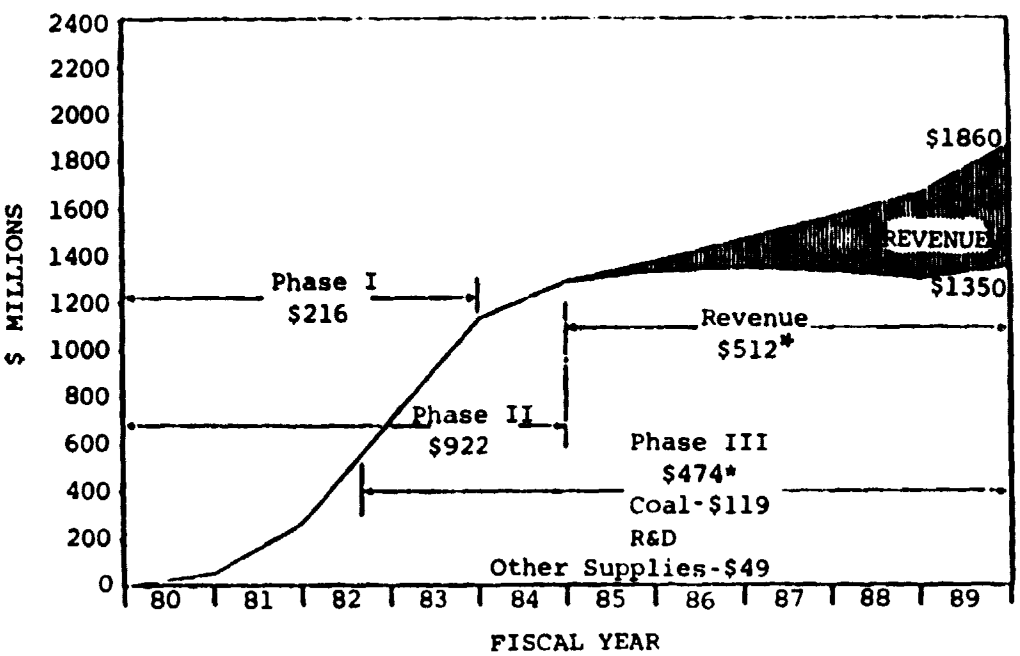
## SRC II DEMONSTRATION PLANT

- CAPACITY: 6000 TONS PER STREAM DAY
- PRODUCTS: FUEL OILS -------- 2050 TPSD
  PIPE LINE GAS ---- 230 TPSD
  LIQUID PROPANE --- 210 TPSD
  BY-PRODUCTS ------ 250 TPSD
- COST: $1.5 BILLION

SRC II

COST ESTIMATE

PHASE I, II, III




*Phase III Coal & Revenue are not escalated

Source: Oak Ridge National Lab

Figure 6-6

## 7.0 REFERENCES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# APPENDIX A

## OVERVIEW OF DOE FOSSIL ENERGY PROGRAM AND MANAGEMENT APPROACH

SRS

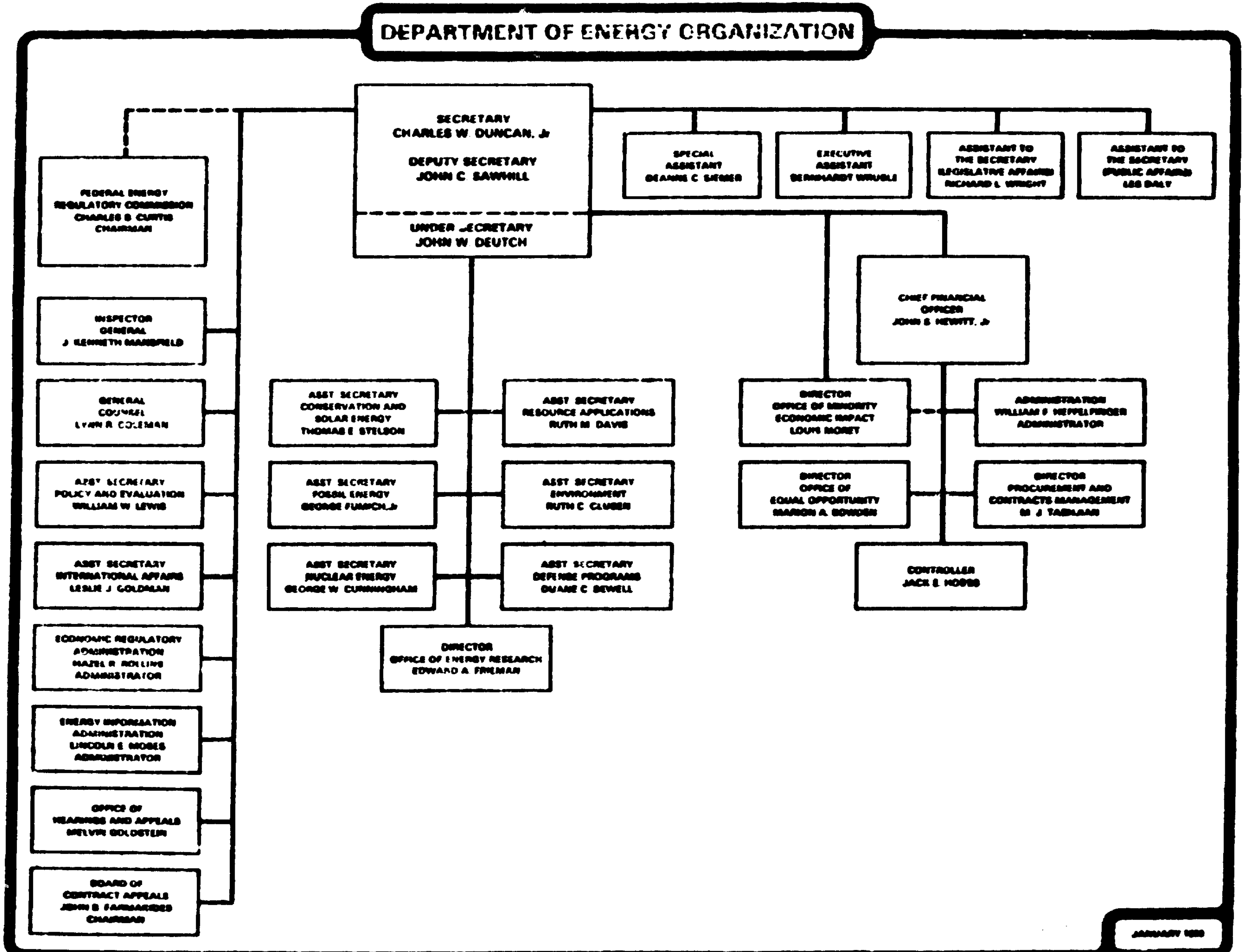
## DOE FOSSIL ENERGY PROGRAMS

- ADDED EMPHASIS ON FOSSIL RESOURCES AND TECHNOLOGIES RESULTED IN ELEVATION OF FOSSIL ENERGY TO ASSISTANT SECRETARY LEVEL IN 1979 (GEORGE FUMICH, FORMER HEAD OF OFFICE OF FOSSIL ENERGY APPROVED BY SENATE AS ASSIST. SEC.)

- MANAGEMENT APPROACH IS FOR HEADQUARTERS TO HANDLE POLICY AND PROGRAM DEVELOPMENT AND FIELD ACTIVITIES TO ASSUME IMPLEMENTATION RESPONSIBILITIES
  - DECENTRALIZATION POLICY (MOVING TECHNICAL MANAGEMENT OF PROJECTS TO FIELD CENTERS) INITIATED IN 1978
  - ETC'S HAVE TRADITIONALLY BEEN RESEARCH ORIENTED

- CREATION OF SYN FUELS CORP. WILL ADD ANOTHER DIMENSION TO COORDINATION AND MANAGEMENT OF DEMONSTRATION AND TECHNOLOGY DEVELOPMENT PROGRAMS

SRS



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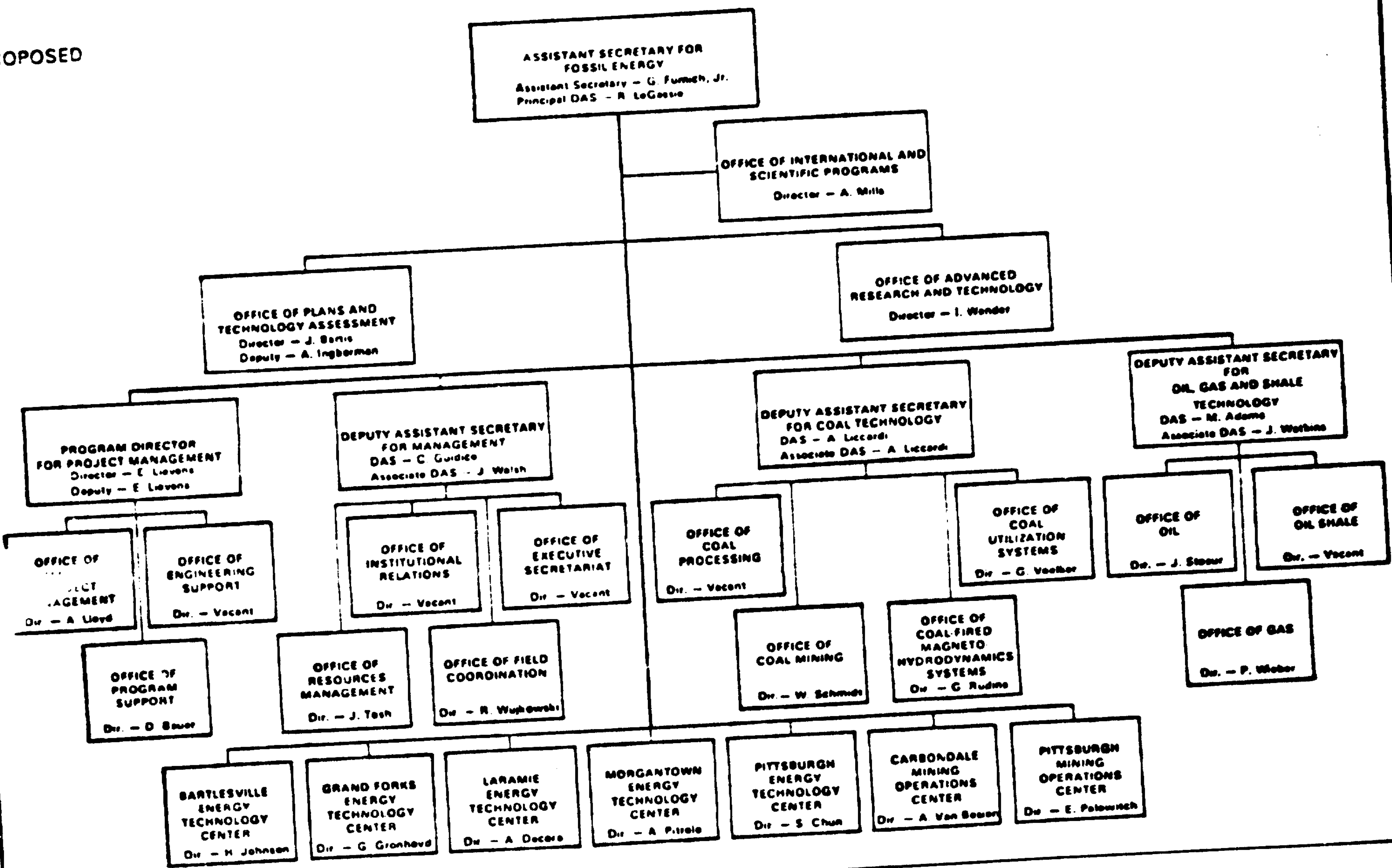
# U.S. DEPARTMENT OF ENERGY
## OFFICE OF ASSISTANT SECRETARY FOR FOSSIL ENERGY

Note: All individuals are acting in the positions shown except the Assistant Secretary



## HEADQUARTERS RESPONSIBILITIES

- PRESCRIBE POLICY FOR THE FOSSIL ENERGY PROGRAM
- DETERMINE THOSE TECHNOLOGIES WHICH WILL BE DEVELOPED
- ESTABLISH AND MAINTAIN LIAISON WITH OTHER ASSISTANT SECRETARIES
- DEVELOP AND MAINTAIN PROGRAM PLANS FOR EACH ASSIGNED AREA
- DEVELOP AND JUSTIFY BUDGETS
- INTERFACE WITH THE OFFICE OF MANAGEMENT AND BUDGET, THE CONGRESS AND OTHER GROUPS THAT INFLUENCE THE PROGRAM
- MEASURE WORK PROGRESS IN THE VARIOUS PROGRAM/PROJECT AREAS AND INFORM DOE MANAGEMENT OF PROGRAM RESULTS
- APPROVE FIELD PROCUREMENT PLANS

SRS

## Program Responsibility by Fossil Energy Office

| FY 1981 PROGRAM STRUCTURE | ASFE ORGANIZATIONS | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | DAS COAL TECHNOLOGY | | | | | DAS OIL, GAS & SHALE TECHNOLOGY | | DAS MGMT | |
| | MAJOR PROJECT MANAGEMENT | COAL UTILIZATION | COAL PROCESSING | MINING | MHD | PETROLEUM | UNCONVENTIONAL GAS | OIL SHALE | BUDGETS & ADMINISTRATION | OFFICE OF PLANS AND TECHNOLOGY ASSESSMENT |
| Mining Research and Development | | | | x | | | | | | |
| Coal Liquefaction | x | | x | | | | | | | |
| Surface Coal Gasification | x | | x | | | | | | | |
| In Situ Coal Gasification | | | | | | | x | | | |
| Advanced Research and Technology Development | | | | | | | | | | |
| • Materials | | | | | | | | | | x |
| • Components, Conversion Processes, Direct Utilization | x | x | x | | | | | | | x |
| • Program Development & Coordination | | | | | | | | | | |
| • University Coal Research | | | | | | | | | x | |
| Advanced Environmental Control Technology | | x | | | | | | | | x |
| Heat Engines and Heat Recovery | | x | | | | | | | | |
| Combustion Systems | | x | | | | | | | | |
| Fuel Cells | | x | | | | | | | | |
| Magnetohydrodynamics | | | | | x | | | | | |
| Enhanced Oil Recovery | | | | | | x | | | | |
| Oil Shale | | | | | | | | x | | |
| Drilling and Offshore Recovery | | | | | | x | | | | |
| Advanced Process Technology | | | | | | x | | | | |
| Enhanced Gas Recovery | | | | | | | x | | | |

Note DAS Deputy Assistant Secretary

PROGRAM IMPLEMENTATION - FIELD ACTIVITIES

- DEVELOPMENT OF INTEGRATED AND INDIVIDUAL PLANS FOR ACTIVITIES AND PROJECTS
- DEVELOPMENT OF PROCUREMENT PLANS
- CHAIRING SOURCE EVALUATION BOARDS AND TECHNICAL ADVISORY COMMITTEES AS APPROPRIATE
- MANAGEMENT OF PROJECTS CONSISTENT WITH MILESTONES AND COSTS
- MAINTAINING AND REPORTING OBLIGATIONS/COSTS ON PROJECT AND PROGRAM BASES
- DEVELOPMENT AND MAINTENANCE OF ADEQUATE TECHNOLOGY BASES FOR EACH PROGRAM AREA
- MANAGEMENT OF APPROPRIATE UNIVERSITY PROJECTS

SRS

## FIELD ACTIVITIES

- DOE FIELD AGENCIES ARE BEING ASSIGNED RESPONSIBLITY FOR IMPLEMENTATION OF FE ACTIVITIES AT THE SUBACTIVITY AND PROJECT LEVELS, INCLUDING CONTRACTING AUTHORITY TO A CERTAIN EXTENT

- LEAD MISSION RESPONSIBILITIES THAT HAVE BEEN DELEGATED TO THE ETC's AND MTC's ARE

BARTLESVILLE ETC
- ENHANCED OIL RECOVERY
- INTERNAL COMBUSTION ENGINE RESEARCH

CARBONDALE MTC
- SURFACE COAL MINING

GRAND FORKS ETC
- "APPLICATIONS CENTER" FOR LOW-RANK COALS

LARAMIE ETC
- OIL SHALE
- IN SITU COAL GASIFICATION
- TAR SANDS

PITTSBURGH ETC
- COAL LIQUEFACTION
- SYNTHETIC FUELS CHARACTERIZATION
- COAL-OIL MIXTURES
- COMBUSTION PHENOMENA
- MHD COMBUSTION

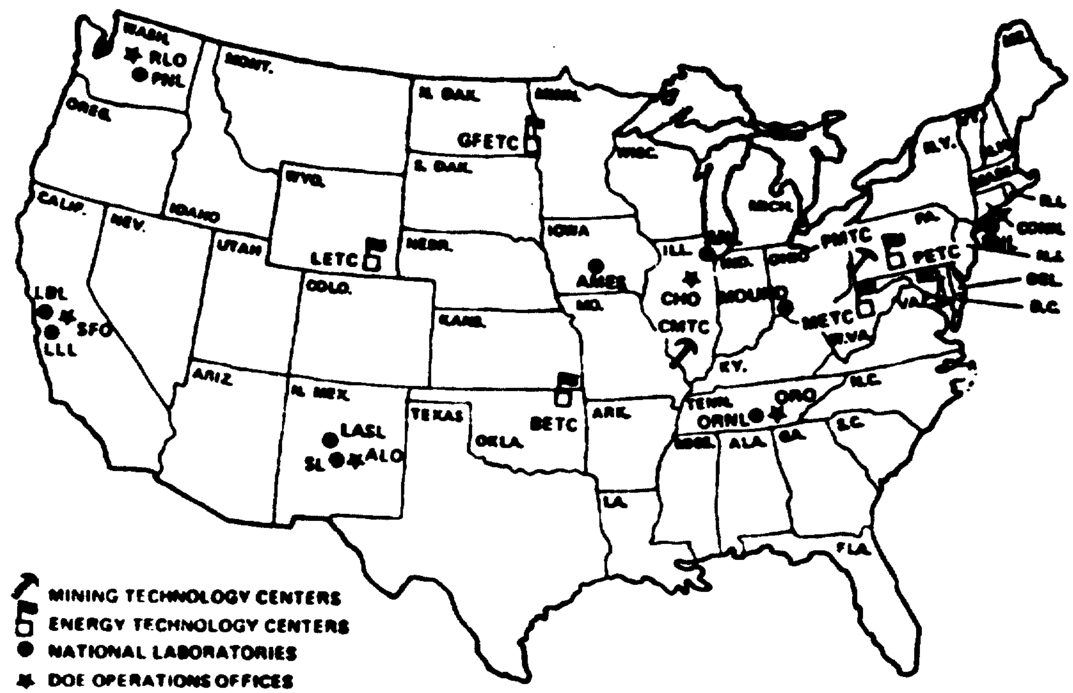
MORGANTOWN ETC
- UNCONVENTIONAL GAS RECOVERY
- FLUIDIZED-BED COMBUSTION
- GAS STREAM CLEANUP & FLUE GAS DESULFURIZATION
- COMBINED-CYCLE COMPONENT INTEGRATION
- SURFACE COAL GASIFICATION
- COMPONENT DEVELOPMENT FOR COAL CONVERSION/ UTILIZATION PROCESSES

PITTSBURGH MTC
- UNDERGROUND MINING
- COAL PREPARATION
- SURFACE TEST FACILITY

- RESPONSIBILITY FOR OTHER SUBACTIVITIES AND PROJECTS SUCH AS FUEL CELLS, ANTHRACITE, ETC. WILL BE DELEGATED TO FIELD AGENCIES AS SPECIFIC PROGRAM PLANS ARE DEVELOPED

SRS

## LOCATION OF DOE FOSSIL ENERGY TECHNOLOGY CENTERS, MINING TECHNOLOGY CENTERS, AND NATIONAL LABORATORIES

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SRS

## Major Field Project Responsibilities and Activities

| FY 1981 PROGRAM STRUCTURE | FIELD AGENCIES | | | | | |
|---|---|---|---|---|---|---|
| | BETC | GFETC | LETC | METC | PETC | OTHERS |
| Mining Research & Development | | | | | | x[1] |
| Coal Liquefaction | | | | | x | |
| SRC I & II | | | | | | x[2] |
| Surface Coal Gasification | | | | x | | |
| Low-Rank Coals (Applic. Center) | | x | | | | x[3] |
| Fuel Gas Demonstration | | | | | | |
| Coal Feeding Systems | | | | x | | |
| In Situ Coal Gasification | | | x | | | |
| Advanced Research and Technology Development | x | x | x | x | x | x[5] |
| Advanced Environmental Control Technology | | | | x | | |
| Gas Stream Cleanup | | | | | | x[6] |
| Heat Engines & Heat Recovery | x | | | x | | |
| Combustion Systems | | | | | | |
| Direct Coal Combustion | | | | | x | |
| Coal Mixtures | | | | | x | |
| Fluidized-Bed Combustion | | | | x | | x[6] |
| Internal Combustion Systems | x | | | | | |
| Fuel Cells | | | | | | |
| Magnetohydrodynamics | | | | | | |
| MHD/CDIF | | | | | | x[4] |
| MHD Combustion | | | | | x | |
| Enhanced Oil Recovery | x | | | | | |
| Oil Shale | | | x | | | |
| Drilling & Offshore Recovery | x | | | | | |
| Advanced Process Technology | x | | | | | |
| Enhanced Gas Recovery | | | | | | |
| Western Tight Gas Sands | x | | | x | | |
| Eastern Gas Shales | | | | x | | |
| Coalbed Methane | | | | x | | |

1 Carbondale MTC/Pittsburgh MTC
2 Oak Ridge Operations
3 Chicago Operations
4 Idaho Operations
5 AL, ANL, BNL, INEL, LASL, LBL, LLL, ORNL, PNL, SL
6 NASA

## FOSSIL ENERGY RESEARCH, DEVELOPMENT AND DEMONSTRATION PROGRAM PARTICIPANTS

- MAJORITY OF RD&D EFFORTS PERFORMED BY PRIVATE INDUSTRY
  - PARTICIPATION INCREASES AS PROJECT OR TECHNOLOGY MATURES FROM BASIC RESEARCH TOWARD DEMONSTRATION PHASES
  - COST SHARING ARRANGEMENTS INCLUDED FOR PILOT PLANT PHASES AND BEYOND
- UNIVERSITY INVOLVEMENT IS EXTENSIVE
  - USUALLY BASIC AND APPLIED RESEARCH (e.g. MATERIALS, COAL STRUCTURE, ENVIRONMENTAL EFFECTS, KINETICS AND MECHANICS OF CONVERSION, ETC.)
  - RESEARCH MAY BE IN DIRECT SUPPORT OF MAJOR PROJECTS OR RELATED TO MORE ADVANCED PROCESSES
  - 129 UNIVERSITIES PARTICIPATING (AS OF JAN. 1980)
- COOPERATIVE ARRANGEMENTS IN PLACE WITH OTHER FEDERAL AGENCIES
  - FOSTER MORE EFFICIENT DEVELOPMENT OF NATIONAL ENERGY PROGRAMS
  - ACTIVITIES OF "MUTUAL BENEFIT TO THE CHARTERS AND GOALS OF THE PARTICIPANTS"

SRS

## MAJOR FOSSIL ENERGY PROGRAMS

- COAL LIQUEFACTION
- SURFACE COAL GASIFICATION
- IN SITU COAL GASIFICATION
- ADVANCED ENVIRONMENTAL CONTROL TECHNOLOGY
- HEAT ENGINES AND HEAT RECOVERY
- COMBUSTION SYSTEMS
- FUEL CELLS
- MAGNETOHYDRODYNAMICS
- ADVANCED RESEARCH & TECHNOLOGY DEVELOPMENT

SRS

## COAL LIQUEFACTION

**OBJECTIVE:** FACILITATE THE ESTABLISHMENT OF A SYNTHETIC FUELS INDUSTRY

**APPROACH:**

- SUPPORT SEVERAL LIQUEFACTION PROCESSES IN PARALLEL FROM LABORATORY SCALE THROUGH PROCESS DEVELOPMENT UNIT AND SELECTING ONLY MOST PROMISING CANDIDATES FOR ADVANCEMENT TO PILOT PLANT STAGE
- DEMONSTRATE THE TECHNICAL CAPABILITY TO COMMERCIALLY PRODUCE CLEAN LIQUID AND SOLID FUELS FROM COAL BY AT LEAST FOUR DIRECT LIQUEFACTION PROCESSES (SRC-I, SRC-II, H-COAL, EDS) BY THE LATE 1980'S
- DEVELOP IMPROVED INDIRECT LIQUEFACTION PROCESSES TO PRODUCE LIQUID FUELS FROM SYNTHESIS GAS MADE FROM COAL BY THE LATE 1980'S
- PROMOTE THE DEVELOPMENT OF MORE ADVANCED THIRD-GENERATION COAL LIQUEFACTION PROCESSES WHICH CAN BE DEMONSTRATED TO BE COMMERCIALLY VIABLE IN THE 1990-2000 TIME FRAME

SRS

## COAL GASIFICATION

**OBJECTIVE:** DEVELOPMENT AND DEMONSTRATION OF THE TECHNOLOGY FOR CONVERTING COAL INTO ALTERNATE PRODUCTS SUITABLE FOR THE DEMANDS OF MANY MARKETS

**APPROACH:** (INTENDED END USES OF HIGH-BTU GASES DIFFER FROM THOSE OF MEDIUM-/LOW-BTU GASES, THUS PROGRAM APPROACHES DIFFER)

### HIGH-BTU PROGRAM

- EVALUATE THE TECHNOLOGICAL AND ECONOMIC STATUS OF EXISTING FIRST-GENERATION PROCESSES AND ASSESS THEIR SUITABILITY FOR MEETING THE U.S. MARKET NEEDS
- PROMOTE THE DEVELOPMENT AND DEMONSTRATION OF NEW AND IMPROVED SECOND-GENERATION TECHNOLOGY FOR COMMERCIAL-SCALE PLANTS TO CONVERT DOMESTIC COALS (CAKING AS WELL AS NONCAKING) TO SYNTHETIC NATURAL GAS OF PIPELINE QUALITY.
- CONTINUE THE DEVELOPMENT OF THIRD-GENERATION GASIFICATION PROCESSES
- PROMOTE COMMERCIAL-SCALE IMPLEMENTATION OF SECOND-GENERATION LOCAL GASIFICATION PROCESSES THROUGH THE CONTINUED IMPLEMENTATION OF THE DEMONSTRATION PLANT PROGRAM FOR HIGH-BTU GASIFICATION

SRS

# COAL GASIFICATION

## LOW-BTU PROGRAM

APPROACH:

- PROMOTE THE DEVELOPMENT AND DEMONSTRATION OF IMPROVED GASIFICATION TECHNOLOGIES FOR COMMERCIAL-SCALE PLANTS TO CONVERT COAL TO ENVIRONMENTALLY ACCEPTABLE GASEOUS FUELS FOR USE IN ELECTRICITY GENERATION, AS AN INDUSTRIAL FUEL, AND AS A CHEMICAL FEEDSTOCK

- ENSURE THAT TECHNOLOGICAL ADVANCES IN LOW-BTU GASIFICATION ARE MADE AVAILABLE TO USERS OF EXISTING COMMERCIAL GASIFICATION SYSTEMS AND PROVIDE OPERATING DATA SUFFICIENT TO ESTABLISH THE CONFIDENCE LEVEL NECESSARY FOR OTHER POTENTIAL INDUSTRIES AND UTILITIES TO USE THIS TECHNOLOGY

- ACQUIRE A COMMERCIAL EXPERIENCE BASE IN SPECIFIC APPLICATIONS OR INDUSTRIES TO ELIMINATE UNCERTAINTIES SUCH AS CAPITAL AND OPERATING COSTS, RETROFIT PROBLEMS AND THE EFFECT OF USING GAS FROM COAL ON THE END PRODUCT

- ESTABLISH THE AVAILABILITY, THROUGH DEVELOPMENT AND/OR DEMONSTRATION, OF CLEANUP EQUIPMENT AND SYSTEMS SUITABLE FOR USE WITH LOW-BTU GASIFIERS IN SATISFYING CURRENT AS WELL AS PROJECTED ENVIRONMENTAL REQUIREMENTS

NOTE: "AS THE ACTIVITIES OF THE HIGH-AND LOW-BTU GASIFICATION PROGRAMS ARE ACHIEVED, THE TECHNOLOGY NEEDED FOR THE PRODUCTION OF MEDIUM-BTU AS WELL AS SYNTHESIS GAS WILL ALSO BE DEVELOPED"

SRS

## IN SITU COAL GASIFICATION

OBJECTIVE: DEVELOP COMMERCIALLY VIABLE UNDERGROUND CONVERSION PROCESSES FOR EXTRACTING ENERGY FROM COAL (APPROXIMATELY 93% OF THE NATION'S COAL RESOURCES IS NOT TECHNICALLY AND ECONOMICALLY RECOVERABLE BY CONVENTIONAL METHODS)

APPROACH:

- DEVELOP AT LEAST ONE COMMERCIAL UNDERGROUND CONVERSION PROCESS BY 1985-1987 AND INSURE TECHNOLOGY TRANSFER TO INDUSTRIAL SECTOR
- DEVELOP ADVANCED CONCEPTS OVER THE LONGER TERM WHICH WILL INCREASE RESOURCE RECOVERY, REDUCE WATER USAGE AND DEPENDENCE ON UNDERGROUND CHARACTERISTICS

FOUR MAJOR PROCESS OPTIONS UNDER DEVELOPMENT:

- A LOW-BTU GASIFICATION PROJECT IS CONCENTRATING ON GASIFYING SHRINKING SUBBITUMINOUS COAL WITH AIR INJECTION AFTER LINKING PAIRS OF WELLS USING REVERSE COMBUSTION
- A PROJECT IS CONCENTRATING ON GASIFYING SHRINKING BITUMINOUS OR SUBBITUMINOUS COAL WITH OXYGEN AND STEAM INJECTION AFTER LINKING PAIRS OF WELLS USING DIRECTIONALLY DRILLED HOLES
- A STEEPLY DIPPING BED (SDB) PROJECT IS CONCENTRATIONG ON GASIFYING COAL SEAMS WHICH DIP MORE THAN 35° AND ARE NOT COMMERCIALLY EXPLOITABLE WITH CONVENTIONAL MINING TECHNOLOGY
- A PROJECT IS CONCENTRATING ON GASIFYING SWELLING BITUMINOUS COALS USING THE BEST AVAILABLE TECHNOLOGY

SRS

## ADVANCED ENVIRONMENTAL CONTROL TECHNOLOGY

**OBJECTIVE:** ASSURE THAT STATIONARY FACILITIES NOW BURNING COAL CAN CONTINUE TO DO SO WHILE MEETING APPLICABLE ENVIRONMENTAL STANDARDS (CLOSE TO 90% OF THE COAL CONSUMED IN THIS COUNTRY IS, AND WILL CONTINUE TO BE, BURNED DIRECTLY) AND SUPPORT COAL CONVERSION PROCESS DEVELOPMENT

**APPROACH:** IDENTIFY, RESEARCH, DEVELOP, REFINE AND DEMONSTRATE A RANGE OF ENGINEERING APPROACHES CAPABLE OF

- REMOVING FLUE GAS POLLUTANTS FOR COMPLIANCE WITH EMISSION STANDARDS
- REMOVING UNDESIRABLE COMPONENTS FROM COAL-DERIVED GAS STREAMS PRODUCED BY GASIFICATION AND/OR COMBUSTION PROCESSES, THUS PROTECTING UTILIZATION EQUIPMENT SUCH AS TURBINES, FUEL CELLS AND HEAT EXCHANGERS

NOTE: SULFUR, NITROGEN, ALKALI AND HALOGEN COMPOUNDS, AND VOLATILE TRACE METAL SPECIES ARE FOUND IN VARYING QUANTITIES IN COAL AND ARE RELEASED THROUGH GASIFICATION AND COMBUSTION PROCESSES. THESE SUBSTANCES CAN DEGRADE THE PERFORMANCE OF ENERGY-PRODUCING SYSTEMS SUCH AS TURBINES AND FUEL CELLS.

SRS

## HEAT ENGINES AND HEAT RECOVERY

**OBJECTIVE:** ADVANCE THE STATE OF THE ART OF HEAT ENGINE SYSTEMS TO PROVIDE A CAPABILITY FOR THE ECONOMICAL AND ENVIRONMENTALLY ACCEPTABLE USE OF COAL AND COAL- OR SHALE-DERIVED FUELS, AND THE DEVELOPMENT OF HEAT RECOVERY SYSTEMS THAT CAN DISPLACE OIL AND GAS FUEL BY CONVERTING RESIDUAL ENERGY TO USEFUL PURPOSES

**APPROACH:**

- CENTRAL POWER SYSTEMS - DEVELOP ADVANCED SYSTEMS FOR DIRECT USE OF COAL BY CENTRAL STATION ELECTRIC UTILITY POWER GENERATION (e.g. INTEGRATED COAL GAS FUELED HIGH-TEMPERATURE TURBINE-COMBINED CYCLE SYSTEM)

- DISPERSED POWER SYSTEMS - DEVELOP INDUSTRIAL SIZE OR SMALL UTILITY SIZE STATIONARY HEAT ENGINE SYSTEMS WHICH CAN OPERATE IN A COGENERATION MODE SIMULTANEOUSLY PRODUCING BOTH ELECTRICITY AND PROCESS HEAT ON THE INDUSTRIAL OR RESIDENTIAL/COMMERCIAL SITE

- HEAT RECOVERY COMPONENT TECHNOLOGY - DEVELOP EFFECTIVE MEANS OF RECOVERING WASTE HEAT THAT IS PRESENTLY BEING REJECTED TO THE ATMOSPHERE OR RIVERS (e.g. CYCLES USING ORGANIC FLUIDS FOR RECOVERING WASTE HEAT FROM STATIONARY DIESELS, GAS TURBINES AND INDUSTRIAL PROCESSES)

SRS

## COMBUSTION SYSTEMS

**OBJECTIVE:** DEVELOP THE TECHNOLOGY REQUIRED FOR THE SUBSTITUTION OF COAL AND COAL-DERIVED FUELS FOR OIL AND GAS AND ENHANCE THE POTENTIAL FOR BURNING COAL CLEANLY AND MORE EFFICIENTLY

**APPROACH:**

- DEVELOPMENT OF FLUIDIZED-BED COMBUSTION (ATMOSPHERIC AND PRESSURIZED) WITH PARTICULAR ATTENTION TO ACHIEVING HIGH COMBUSTION EFFICIENCY, ACCEPTABLE COMPONENT DURABILITY, MINIMUM EMISSION OF PARTICULATES AND SULFUR AND NITROGEN OXIDES, AND RELIABLE OPERATION OF COMBINED-CYCLE SYSTEMS

- DETERMINATION OF COMBUSTION AND HEAT TRANSFER CHARACTERISTICS OF CHARS, COAL-OIL MIXTURES (COMs), SOLVENT REFINED COAL, AND COAL-DERIVED LIQUID FUELS WHEN BURNED IN CONVENTIONAL EQUIPMENT AND THE APPLICATION OF SUCH DATA TO IMPROVED COMBUSTION COMPONENT DESIGN

- DETERMINATION OF CAUSES OF ADHERENT SLAG AND ASH DEPOSITS, AND DEVELOPMENT OF METHODS FOR MINIMIZING THESE RELIABILITY AND EFFICIENCY DEGRADING PROBLEMS

- IDENTIFICATION AND CONTROL OF TOXIC ELEMENTS EVOLVED DURING THE DIRECT COMBUSTION OF COAL

SRS

## FUEL CELLS

OBJECTIVE: NEAR TERM - ESTABLISH THE COMMERCIAL FEASIBILITY OF FUEL CELL POWER PLANTS FOR ELECTRIC UTILITY APPLICATIONS AND INDUSTRIAL COGENERATION ON-SITE TOTAL ENERGY SYSTEMS

LONGER TERM - DEVELOP ADVANCED, HIGHER EFFICIENCY, ECONOMICALLY COMPETITIVE FUEL CELL TECHNOLOGIES FOR ALL END-USE APPLICATIONS

APPROACH:

- 4.8 MW ELECTRIC UTILITY POWER PLANT DEMONSTRATION: ON A UTILITY GRID, TEST THE OPERATIONAL FEASIBILITY AND FULL-SCALE SYSTEM INTEGRATION OF EARLY DESIGN (1976) ELECTRIC UTILITY FUEL CELLS
- PHOSPHORIC ACID SYSTEMS DEVELOPMENT: DEVELOP FUEL CELL SYSTEMS FOR OS/IES APPLICATIONS AND PROVIDE TECHNOLOGY TO LOWER COST AND INCREASE RELIABILITY OF PHOSPHORIC ACID FUEL CELL SYSTEMS FOR BOTH ELECTRIC UTILITY SERVICE AND OS/IES APPLICATIONS
- MOLTEN CARBONATE SYSTEMS DEVELOPMENT: ADVANCE THE STATE OF THE ART OF MOLTEN CARBONATE FUEL CELLS TO ACHIEVE THE EARLIEST POSSIBLE COMMERCIALIZATION OF COAL-FUELED POWER PLANTS IN ELECTRIC UTILITY BASE LOAD AND INDUSTRIAL COGENERATION APPLICATIONS
- FUEL CELL ADVANCED SYSTEMS: SUPPORT EMERGING SYSTEMS WITH A SUFFICIENT TECHNOLOGY BASE, EXAMINE ADVANCED FUEL CELL SYSTEMS THERMIONICS, AND BROADEN THE SPECTRUM OF ACCEPTABLE FUELS

SRS

## MAGNETOHYDRODYNAMICS

**OBJECTIVE:** FACILITATE THE COMMERCIALIZATION OF MHD ELECTRIC POWER PLANTS THROUGH THE DESIGN, CONSTRUCTION AND OPERATION OF A 500 $MW_t$ COMMERCIAL PROTOTYPE MHD POWER PLANT (ENGINEERING TEST FACILITY - ETF)

**APPROACH:**

- OPEN-CYCLE SYSTEMS - DESIGN, CONSTRUCT AND OPERATE A FULLY INTEGRATED, COMBINED-CYCLE MHD/STEAM SYSTEM DRAWING ON SUPPORTING RESEARCH AND DEVELOPMENT FOCUSED TOWARD IDENTIFIED REQUIREMENTS AND COMPONENT AND SUBSYSTEM QUALIFICATION TESTING (AT COMPONENT DEVELOPMENT AND INTEGRATION FACILITY - CDIF)

- CLOSED-CYCLE SYSTEMS - PERFORM SYSTEMS ENGINEERING STUDIES WHICH WILL PROVIDE AN ASSESSMENT OF CLOSED-CYCLE MHD POWER PLANTS AND ASSOCIATED TECHNOLOGY REQUIREMENTS, EXPERIMENTAL STUDIES OF THE COMPATIBILITY OF A COAL-FIRED COMBUSTOR WITH A REGENERATIVE HEAT EXCHANGER, DESIGN OF A MAJOR BLOW-DOWN EXPERIMENT OF A 25 $MW_t$ INPUT

SRS

## ADVANCED RESEARCH AND TECHNOLOGY DEVELOPMENT

OBJECTIVE: PROVIDE BASIC/APPLIED RESEARCH AND DEVELOPMENT

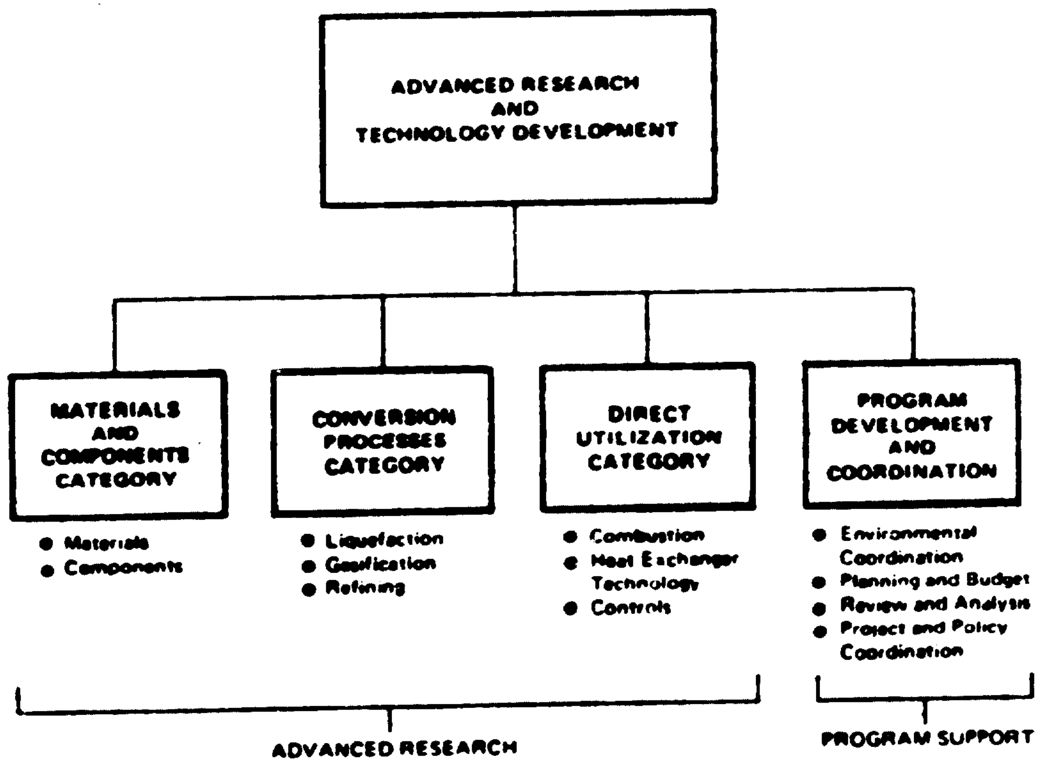
APPROACH:

- PROVIDE FOR A CENTRAL RESEARCH FOCUS AND PROGRAM COORDINATION FOR ALL PROGRAM AREAS OF FOSSIL ENERGY
- PROVIDE A FOUNDATION FOR INNOVATIVE TECHNOLOGY LEADING TO ADVANCED PROCESSES THROUGH PROGRAMS IN THE DOE ENERGY TECHNOLOGY CENTERS (ETCs), NATIONAL LABORATORIES (NLs), OTHER GOVERNMENT AGENCIES, PRIVATE INDUSTRY, AND UNIVERSITIES
- FACILITATE RELIABLE AND EFFICIENT OPERATION OF SYNTHETIC FUEL PLANTS THROUGH MATERIALS AND COMPONENTS RESEARCH
- ACCELERATE DIRECT UTILIZATION OF COAL OR COAL-DERIVED SYNFUELS THROUGH TECHNOLOGY DEVELOPMENT FOR COMBUSTION SYSTEMS, HEAT EXCHANGERS AND CONTROL SYSTEMS, INCLUDING APPLICATIONS TO HEAT ENGINES AND FUEL CELLS
- ENSURE AN ADEQUATE SUPPLY OF TRAINED TECHNICAL PERSONNEL FROM THE NATION'S UNIVERSITY SYSTEM
- ASSESS THE VIABILITY OF FOSSIL ENERGY PROCESSES UNDER DEVELOPMENT IN TERMS OF NATIONAL NEEDS, ECONOMIC, SOCIAL AND ENVIRONMENTAL CONSTRAINTS AND BENEFITS
- PROVIDE TECHNICAL ASSESSMENT, ENVIRONMENTAL AND SYSTEMS ASSURANCE SUPPORT FOR FOSSIL ENERGY PROGRAMS

SRS

DEPARTMENT OF ENERGY

FOSSIL ENERGY



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| ADVANCED RESEARCH AND TECHNOLOGY DEVELOPMENT | BUDGET AUTHORITY (DOLLARS IN THOUSANDS) | | |
|---|---|---|---|
| SUBACTIVITIES | ACTUAL FY 1979 | APPROPRIATION FY 1980 | ESTIMATE FY 1981 |
| Processes | 7,850 | 14,800 | 20,400 |
| Direct Utilization | 9,450 | 7,100 | 11,000 |
| Materials and Components | 9,290 | 12,900 | 9,000 |
| Program Development and Coordination | 13,158 | 7,700 | 7,861 |
| University Coal Research | 0 | 5,000 | 5,000 |
| Capital Equipment | 375 | 400 | 500 |
| Construction | 6,350 | 8,250 | 10,700 |
| TOTAL | 46,473 | 56,150 | 64,461 |

## ADVANCED RESEARCH AND TECHNOLOGY DEVELOPMENT

- OFFICE OF ADVANCED RESEARCH AND TECHNOLOGY PROVIDES OVERSIGHT ON ALL ASPECTS OF ADVANCED RESEARCH AND MANAGES A NEWLY ESTABLISHED UNIVERSITY COAL RESEARCH PROGRAM

- APPLIED RESEARCH IS THE RESPONSIBLITY OF THE RESPECTIVE OFFICES HAVING PRIMARY COGNIZANCE
  - MATERIALS: OFFICE OF ADVANCED RESEARCH AND TECHNOLOGY
  - COMPONENTS AND CONVERSION PROCESSES: OFFICE OF COAL PROCESSING
  - DIRECT UTILIZATION: OFFICE OF COAL UTILIZATION

- SUPPORT FOR PROGRAM DEVELOPMENT AND COORDINATION IS PROVIDED BY:
  - OFFICE OF BUDGETS AND ADMINISTRATION: LONG-TERM STRATEGY AND PLANNING, PROGRAM REVIEW AND ANALYSIS, FINANCIAL PLANNING, AND PROGRAM INTEGRATION SUPPORT
  - OFFICE OF PLANS AND TECHNICAL ASSESSMENT: PROCESS ENGINEERING, ECONOMICS, AND ALL ASPECTS OF ENVIRONMENTAL PLANNING AND ASSESSMENT COVERING ALL FOSSIL ENERGY FACILITIES AND PROGRAMS

SRS

# APPENDIX B.

# COAL CONVERSION SYSTEM AND PROCESS MODELING REVIEW

SRS

As an additional task to the major study effort, a survey and assessment was conducted of available coal conversion and process modeling systems. The areas of interest centered on high-level system models, dynamic models, steady-state point models, and cost estimation models.

Table I summarizes the major findings of this assessment; a more detailed discussion follows.

ASPEN (Advanced System for Process Engineers) is a DOE sponsored effort being performed by the Massachusetts Institute of Technology. Originally begun in 1976, the program began extensive system testing in 1979. Representatives from industry and government were invited to participate in the system test for a fee of $15,000 or $25,000. At the conclusion of this test phase in 1981, the ASPEN source code will be made available at no cost.

The goal for ASPEN is to be the next generation process simulator and economic evaluation system. The flowsheet of a proposed or operating plant will be simulated by ASPEN by performing detailed heat and material balances. In addition, equipment sizing and preliminary estimates of capital and operating costs will be performed. The project is funded by the U.S. Department of Energy, which will use ASPEN to evaluate process alternatives for fossil energy conversion and synthetic fuels manufacture.

ASPEN is tailored for coal gasification studies. The system data base is excellent and contains current data. The system support provided includes training classes conducted by the MIT staff and ASPEN maintenance training.

LSP (Large Scale Steady State Program) is a DOE sponsored effort performed at Purdue University between 1976 and 1979. The source code and user manuals are available at a cost of $2,000. LSP provides a steady-state point estimate model of a

process which is described as a flowsheet. This program was built as a parallel effort to the Lehigh DSS/2 program. The main problem with LSP is its limited data base and minimal system support.

DSS/2 (Differential Systems Simulator Version 2) is a DOE sponsored effort performed at Lehigh University between 1976 and 1979. The source code and user manuals are available at a relatively low cost. DSS/2 provides a dynamic model of a process which must be described as a system of differential equations. The main problems with DSS/2 appear to be its limited data base, its difficulty to use, and its limited system support.

CHEMSHARE and PROCESS are two commercially available programs which have been used extensively. The user pays a small initial charge and then pays a charge for time used. Access to the program source code is prohibited, although the experienced user can include his own subroutines. These programs are thoroughly tested and have a readable data base.

MPPM (Materials-Process-Product Model) is a DOE sponsored program written by International Research and Technology Corp. This program provides a high-level system modeling capability and has been used to model coal gasification processes. The user may obtain access to the source code at no cost. Training and system support is provided. The problem with MPPM appears to be inaccurate algorithms employed in some of the models.

CHESS (CHemical Engineering Simulation System) is a program written at the University of Houston. It appears that CHESS has had limited continual support and as such would be unacceptable for use today.

A Morgantown Energy Technology Center (METC) internal report (IR No. 868): Inventory of METC Computer Models, Process Modeling Capabilities, and System Simulation Capabilities describes the available software in detail. Available software includes:

1. Unit operation models
2. Physical property data bases
3. Mathematical packages
4. Process simulators
5. Economics and cost estimation models
6. Fossil-fuel utilities analysis
7. Technical data bases.

From these main areas, the software shown in Table II was identified as being applicable to the areas of NASA/MSFC interest.

The METC survey and the SRS assessment complement each other in that certain modeling programs, e.g., PROCESS, CHEMSHARE, MPPM, etc., are not included in the METC survey, whereas they are addressed in the SRS assessment.

## RECOMMENDATIONS

The general findings of this assessment are that the commercial products, CHEMSHARE, PROCESS, etc., do not allow user access to source codes. Use of these programs are sold on a low initial cost with a charge for time used. The DOE sponsored programs appear to be more useful to potential NASA/MSFC applications. ASPEN appears to be the best overall tool of the DOE programs. However, the ASPEN source will not be publicly available until October 1981. Current usage of ASPEN requires a payment of $15,000 or $25,000. When ASPEN testing is complete, the program will be available at no cost. The MPPM program gives a high level system modeling capability. A partial list of the general processes supported by MPPM is given in Table III.

The SRS recommendation to NASA/MSFC is that MPPM be used initially to develop high level system models and that ASPEN be used in 1981 to perform the detailed design analysis.

| PROGRAM NAME | DEVELOPED BY | SPONSOR | STATUS | ACQUISITION COST | SOURCE CODE ACCESS | COMMENTS |
|---|---|---|---|---|---|---|
| ASPEN | MIT | DOE | TEST | $25,000 | NO | ASPEN will be available at no cost in October 1981. This system has extensive support and training. ASPEN has a very good data base, appears to be easy to use, and is tailored for gasification studies. |
| LSP | PURDUE | ERDA /DOE | COMPLETE | $2,000 | YES | LSP is a steady-state program. A limited data base and unknown system support make this system unattractive. |
| DSS/2 | LEHIGH | ERDA /DOE | COMPLETE | MINIMAL | YES | DSS/2 is a dynamic system model built in parallel with LSP. The user must input the differential equations which describe the system. A limited data base and unknown support make this system unattractive. |
| CHEMSHARE | CHEMSHARE, INC. | COMMERCIAL | COMPLETE | TIME CHARGE | NO | CHEMSHARE is a commercial product that has been used for several years. |
| PROCESS | SIMULATION SCIENCES, INC. | COMMERCIAL | COMPLETE | TIME CHARGE | NO | PROCESS is a commercial product that has been used for several years. |
| MPPM | INTERNATIONAL RESEARCH & TECHNOLOGY CORP. | DOE | ON-GOING DEVELOPMENT | FREE | YES | MPPM has several processing models which are described later. This program provides a top-level systems model. |
| CHESS | UNIVERSITY OF HOUSTON | | COMPLETE | | | CHESS has limited support and appears to be inadequate for gasification studies. |

Table 1

## TABLE II

### Unit Operations Models

I. Chemical Equilibrium Models

ASPEN Chemical Equilibrium Code

- minimizing Gibbs Free Energy
- using equilibrium constants

II. Solids Handling and Separation

ASPEN Crusher
ASPEN Screen
ASPEN Rotary Vacuum Filter
ASPEN Filtering Centrifuge

III. Gas Cleanup

ASPEN Cyclone
ASPEN Hydrocyclone
ASPEN Baghouse
ASPEN Venturi
ASPEN Electrostatic Precipitator

IV. Simple Reactor Models

ASPEN Stoichiometric Reactor
Purdue Stoichiometric Reactor
ASPEN Yield Reactor

V. Flashes

ASPEN Three-Phase Flash
Purdue Three-Phase Flash
ASPEN Two-Phase Flash
Two-Phase Flash by Systems Simulations, Inc.
Purdue Two-Phase Flash

VI. Multistaged Separation

ASPEN Liquid-Liquid Extraction
ASPEN Absorber/Stripper
SSI Absorber/Stripper
Purdue Absorber/Stripper
Purdue Acid Gas Absorber/Stripper
ASPEN Distillation Columns (Shortcut)
ASPEN Distillation Columns (Rigorous)

TABLE II - (Continued)

VII. Heat Exchangers

ASPEN General Purpose Heater
SSI Heat Exchanger

VIII. Other Models

Lehigh Dynamic Bulk Methanation
Lehigh Dynamic $H_2$ Plant Dynamic Model
Purdue Steam-$H_2$ Reformer
Purdue Oil Hydrotreater

## TABLE III

## MPPM Supported Processes

Low-Btu Gasification
Medium-Btu Gasification
Medium-Btu Gasification-Hydrogenation
Liquefaction
Methane Synthesis
Methanol Synthesis
Ammonia Synthesis
Shift Conversion
Gas Purification (Pre-shift)
Hydrogen Purification
Coal Preparation
Mineral Preparation
Oxygen Production
Coal Breaking, Cleaning, and Stockpiling
Coal Fines Preparation
Hot Gas Clean-up (Low-Btu)
Industrial Boiler
Utility Boiler
UC Gasifier
Combined Cycle Electric Power Generator & Boiler
Flue Gas Clean-up
Sulfuric Acid
Cold Gas Clean-up (Low-Btu)
Water Clean-up
Steam Turbine Electric Power Generation
Waste Heat Disposal
On-Site Electric Power Generation
Waste Disposal
Methane Reformaticn
Char Gasification
Gas Purification, Post-shift
Sulfur Recovery (Gases)
Sulfur Recovery (Solids)